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## THESIS

INTEGRATION OF THE EXECUTION  
SUPPORT SYSTEM FOR THE  
COMPUTER-AIDED PROTOTYPING SYSTEM (CAPS)

by

Frank V. Palazzo

September 1990

Thesis Advisor:

Luqi

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Integration of the Execution  
Support System for the  
Computer-Aided Prototyping System (CAPS)

by

Frank V. Palazzo  
B.S., Fordham University, 1980

Submitted in partial fulfillment  
of the requirements for the degree of

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## ABSTRACT

With the rapidly falling cost of computer hardware continuing to drive software expenses up, attention has turned to ways to effect savings. One approach that shows particular promise is rapid prototyping. Rapid prototyping is the use of executable models of a software system to firm up the requirements before a significant amount of time and effort has been invested in implementation. The computer-aided prototyping system (CAPS) is a rapid prototyping system that automates many of the manual processes of prototyping, thus allowing for quicker prototype construction and even further cost savings.

Within CAPS there exists an execution support system. The purpose of the execution support system is to take the description of a prototype written in the prototyping language PSDL and to convert this into an executable prototype which can then be shown to the user. Previous research resulted in separate implementations for the components of the execution support system, but these components were never integrated into a functioning system.

It is the development of this tool which is the subject of this thesis.

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## I. INTRODUCTION

As the cost of computer hardware continues to decline, total software costs continue to grow rapidly as we uncover more and more problem domains that demand an automated solution. In the early 1970s, total software costs for the Department of Defense exceeded \$3 billion; it is predicted that in 1990 total software costs for embedded computer systems alone will exceed \$32 billion [Ref. 1:p. 8]. According to one economic study, costs related to software accounted for about 2% of the U.S. gross national product in 1980, or about \$40 billion [Ref. 2]. According to a more recent estimate, software related expenses had risen to about 5% of the U.S. GNP in 1986, or about \$228 billion [Ref. 3].

As the rapidly falling cost of computer hardware continues to drive software costs up, where can savings be effected? One area where significant savings can probably be realized is in the area of software maintenance. Software maintenance is defined as the changes that are made to an existing software system. Reports vary on the actual

figures, but its estimated that industry spends from 40% to 75% of its total hardware and software monies on software maintenance [Ref. 4]. But why are software systems changed?

Software systems are changed for the following reasons:

#### New situations

Changes in the environment of the system have introduced new requirements. Examples of such changes are new external systems, new policies, new technologies, and new competitive pressures.

#### User education

Customer requirements have changed because experience with the current version of the system has changed their perception of how computers can be used to solve their problems.

#### Phased delivery

A partial implementation has been delivered because the customer cannot wait until a complete implementation is available.

#### Requirements errors

The developers have incorrectly understood the requirements and have produced a system that does not meet user needs.

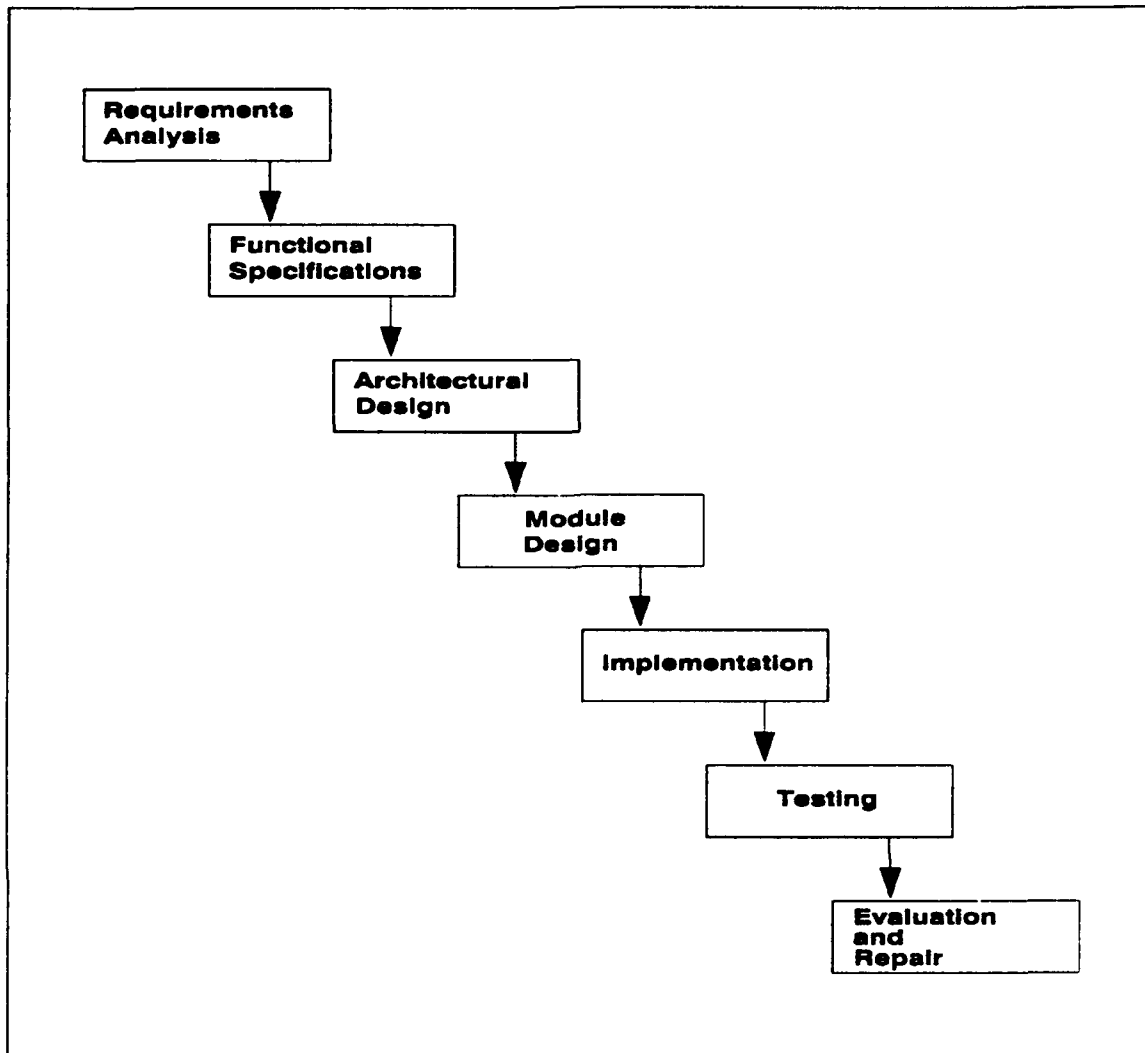
#### Implementation errors

A faulty design or implementation does not correspond to the specification. [Ref. 3:p. 2-3]

One approach that can help reduce maintenance costs is rapid prototyping. A prototype is an executable model or

pilot version of the intended software system. A prototype is usually a partial representation of the intended system, used as an aid in requirements analysis rather than as production software. The rapid construction activity leading to such a prototype is called rapid prototyping. Prototypes can help customers visualize and test consequences of their requirements, thus allowing the requirements to be stabilized before a significant amount of time and effort has been invested in implementation. [Ref. 6]

The traditional software life cycle consists of a series of phases which yield runnable software only late in the process. One view of the traditional life cycle is illustrated in Fig. 1. A major problem with the traditional approach is that there is no guarantee that the resulting product will meet the customer's needs. Often users will be able to indicate the true requirements only by observing the operation of the system, and the traditional life cycle yields executable programs late in the process, when too much money has already been spent. [Ref. 5:p. 5-6]



**Fig. 1 Traditional Software Life Cycle**

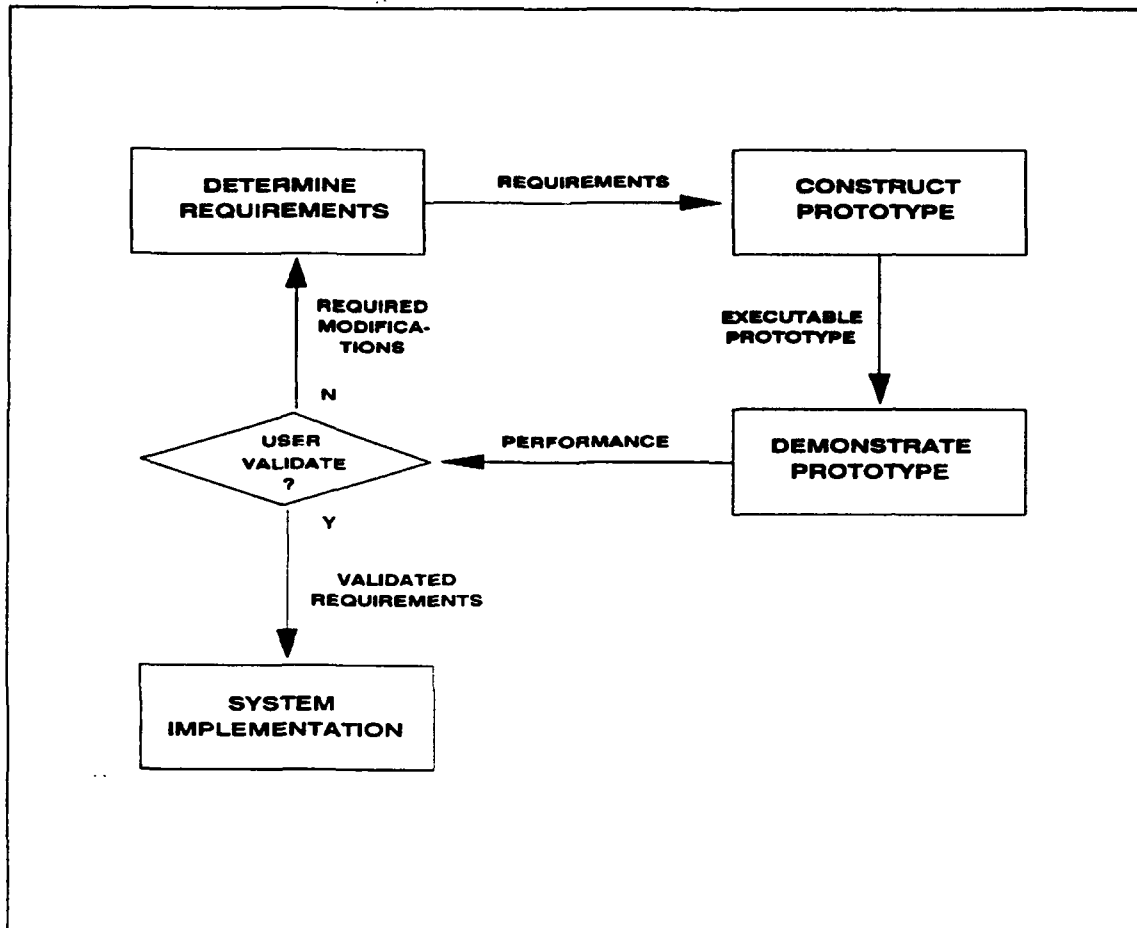
This problem is even more exacerbated in the case of hard real-time or embedded systems, where the potential for inconsistencies is greater. One of the major differences between a real-time computer system and a conventional system is the required precision and accuracy of the application software. The response time of each individual



operation may be a significant aspect of the associated requirements, especially for operations whose purpose is to maintain the state of some external system within a specified region, as is common in these types of systems. These response times, or deadlines, must be met or the system will fail to function, possibly with catastrophic consequences. These requirements, which will often exceed the intellectual capacity of a single software engineer, can be very difficult to determine. [Ref. 5:p. 6-7]

Current research suggests a revised software development life cycle based on rapid prototyping. This prototyping life cycle is an alternative to the traditional life cycle which has been proposed to alleviate problems stemming from incorrect requirements, especially when designing hard real-time or embedded systems. As a software development methodology, rapid prototyping provides the user and designer with a fast, efficient and easy-to-use stepwise process. When utilized during the early stages of the development life cycle, rapid prototyping allows validation of the requirements, specifications and initial design before valuable time and effort are expended on

implementation software. Fig. 2 graphically depicts this



**Fig. 2 Rapid Prototyping Loop**

methodology as a feedback loop. Rapid prototyping is an iterative process that starts out with the user defining the requirements for the critical aspects of the envisioned system. Based on these requirements, the designer then

constructs a model or prototype of the system in a high-level, prototype description language and examines the execution of this prototype together with the user. If the prototype fails to execute properly, the user then redefines the requirements and the prototype is modified accordingly. This process continues until the user determines that the prototype successfully meets the critical aspects of the envisioned system. Following this validation, the designer uses the validated requirements as a basis for the design of the production software. [Ref. 5:p. 7-9]

While rapid prototyping has been found to be an effective technique for clarifying requirements and eliminating a large amount of wasted effort currently spent on developing software to meet incorrect or inappropriate requirements, the addition of computer aid would make rapid prototyping even more beneficial. The computer-aided prototyping system (CAPS) is a prototyping system which provides this capability. Designed to operate on the prototyping language PSDL (Prototype System Description Language), CAPS provides the designer with an integrated set of tools to support prototyping of complex software systems which may include

hard real-time constraints [Ref. 5:p. 9]. These tools include an execution support system, a rewrite system, a syntax-directed editor with graphics capabilities, a software base, a design database, and a design-management system [Ref. 7:p. 66]. It is the integration of the execution support system which is the focus of this thesis.

The prototyping language PSDL, along with the prototyping method are examined in Chapter II. An overview of CAPS is given in Chapter III. Integration of the execution support system is discussed in Chapter IV. A complete prototype example is provided in Chapter V. Conclusions are presented in Chapter VI.

## **II. LANGUAGE AND METHOD**

### **A. LANGUAGE**

A good language for expressing design thoughts in terms of a precise model is important for rapid prototyping. It is impossible to do a good design without a language designed especially for this purpose. A powerful, easy-to-use, and portable prototype-description language is a critical part of a computer-aided prototyping system. Such a language is needed before the tools in the system can be built. [Ref. 7:p. 68]

PSDL was designed together with the prototyping method to ensure the most efficient use of the language. It serves as an executable prototyping language at a specification or design level and has special features for real-time system design. [Ref. 7:p. 68]

#### **1. The PSDL Computational Model**

The PSDL language is based on a computational model which treats software systems as networks of operators communicating via data streams. The computational model is an augmented directed graph

$$G=(V,E,T(v),C(v))$$

where  $V$  is the set of vertices,  $E$  is the set of edges,  $T(v)$  is the set of timing constraints for each vertex  $v$ , and  $C(v)$  is the set of control constraints for each vertex  $v$ . Each vertex is an operator and each edge is a data path. Each of the four components of the graph are described in more detail below. The semantics of a PSDL system description is determined by the associated augmented graph and the semantics of the operators appearing in the diagram. [Ref. 8:p. 2]

#### **a. Operators**

All PSDL operators are either FUNCTIONS or STATE MACHINES. When an operator fires, it reads one data value from each of its input streams, and writes at most one data value on each of its output streams. The output objects produced when a function fires depend only on the current input values. The output values produced when a state machine fires depend only on the current input values and the current values of a finite number of internal STATE VARIABLES. [Ref. 6:p. 1411-1412]

Each operator is either ATOMIC or COMPOSITE. Atomic

operators are operators which cannot be decomposed any further. Composite operators are operators which have realizations as data and control flow networks of lower level operators. A composite operator whose network contains cycles is a state machine. In such a case, one of the data streams in each cycle is designated as the state variable controlling the feedback loop, and an initial value is specified for it. The state variables serve to break the circular precedence relationships among the operators which would otherwise be implied. In the example shown below, there is a cycle consisting of the streams S and Y. The stream X is the only input to the network, and Z is the only output. [Ref. 6:p. 1412]

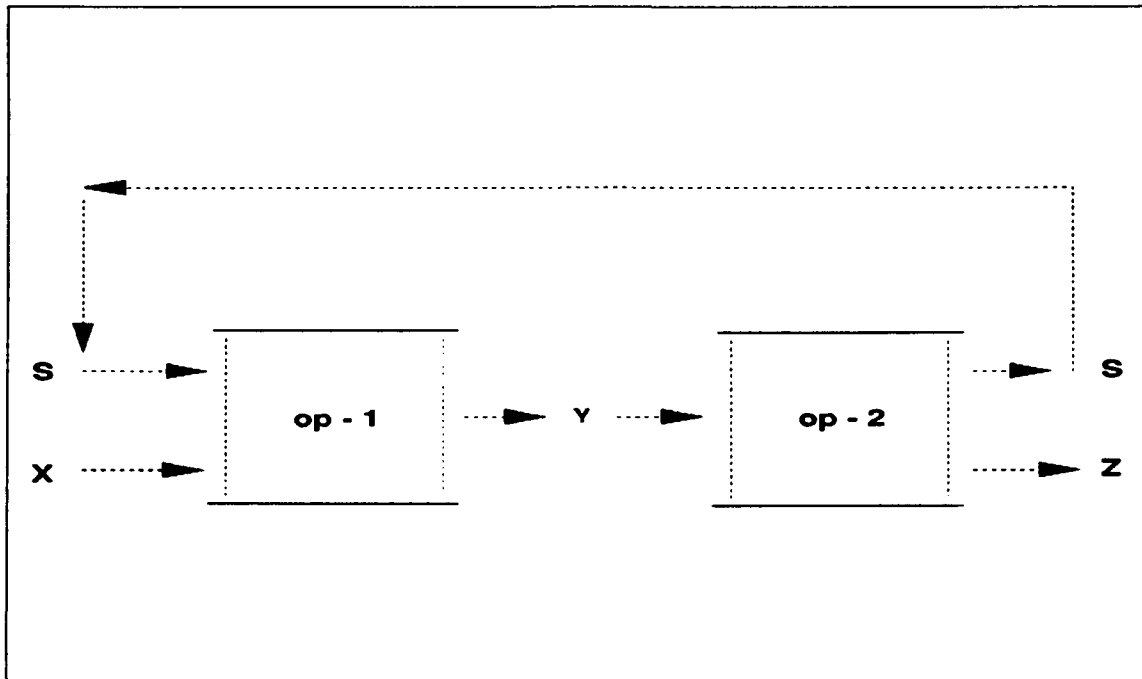
In PSDL, S would be designated as the state variable of this cycle by including the following

states S initially S-0

in the specification part of the composite operator. S-0 gives the initial value for S. [Ref. 6:p. 1412]

#### **b. Data Streams**

PSDL operators communicate by means of data streams. A data stream is a communication link connecting exactly one



**Fig. 3. A simple state machine.**

producer operator to exactly one consumer operator. In Fig. 3, Y is a data stream from producer op-1 to consumer op-2. Each stream carries a sequence of data values of an abstract data type. Streams have the pipeline property: if a and b are two data values in data stream Y and the data value a is generated by op-1 before value b is generated then it is



impossible for a to be delivered to op-2 after b is delivered. [Ref. 6:p. 1412]

There are two types of data streams in PSDL-DATA FLOW STREAMS and SAMPLED STREAMS. Dataflow streams are used in applications where the values in the stream must not be lost or replicated, while sampled streams are used in applications where a value must be available at all times and values can be replicated without affecting their meaning. A dataflow stream can be thought of as a fifo queue of length one, while a sampled stream can be thought of as a cell capable of containing just one value, which is updated whenever the producer generates a new value. [Ref. 6:p. 1412]

Dataflow streams guarantee that each of the data values written into the stream is read exactly once. Computation sequences that would require a value to be written into a full queue or to be read from an empty queue result in an error message. While computation sequences that would require a value to be written to a non-empty sampled stream are valid, attempts to read from an uninitialized sampled stream are not, and will result in an

error message. Thus, this type of error can be avoided by declaring initial values for sampled streams. [Ref. 8:p. 3-4]

### **c. Timing Constraints**

Any PSDL operator can have timing constraints associated with it. An operator is **time-critical** if it has at least one timing constraint associated with it, and is **non time-critical** otherwise. The timing constraints together with the control constraints determine when the operator can be fired, and when it must be fired. There are several different kinds of timing constraints. [Ref. 8:p. 4] The most basic are given in the specification part of a PSDL module, and consist of the **MAXIMUM EXECUTION TIME**, the **MAXIMUM RESPONSE TIME**, and the **MINIMUM CALLING PERIOD** [Ref. 6:p. 1416].

Every time-critical operator must have a **maximum execution time (MET)** to allow the construction of a static schedule. The MET of an operator is an upper bound on the length of time between the instant when a module begins execution and the instant when it completes, called the **execution interval (EI)**. All of the actions that may be

required to fire an operator once must fit into the execution interval. These actions are listed below.

- (1) Reading values from input data streams.
- (2) Evaluating triggering conditions.
- (3) Calculating output values.
- (4) Evaluating output guards.
- (5) Writing values into output streams. [Ref. 8:p. 4-5]

Operators triggered by temporal events are periodic in PSDL. Every periodic operator must have a **period** (PERIOD) and may have a **deadline** (FINISH\_WITHIN). These two timing constraints partially determine the set of **scheduling intervals** (SI) for the operator. Each periodic operator must be fired exactly once in each scheduling interval, and must complete execution before the end of the scheduling interval. The period is the length of time between the start of any scheduling interval and the start of the next scheduling interval. The deadline is the length of each scheduling interval. The starting time of the first scheduling interval for each operator is determined by the static scheduler. [Ref. 8:p. 5]

The relation between the timing constraints, scheduling intervals, and execution intervals for a periodic

operator is illustrated in Fig. 4. The execution intervals and scheduling intervals in the diagram are indexed by integers in the order of their occurrence. Thus  $SI[n]$  denotes the  $n$ -th scheduling interval for the operator and  $EI[n]$  denotes the  $n$ -th execution interval for the operator.

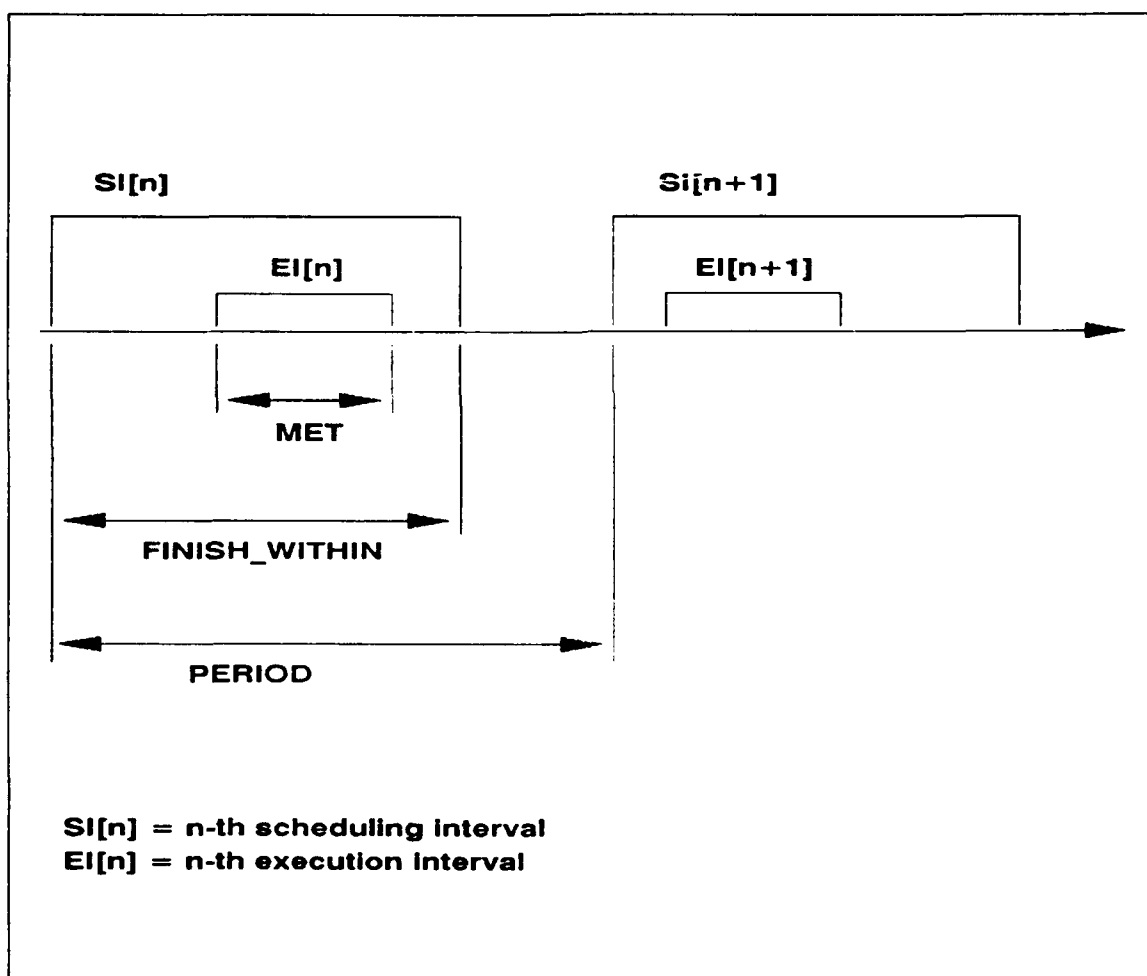
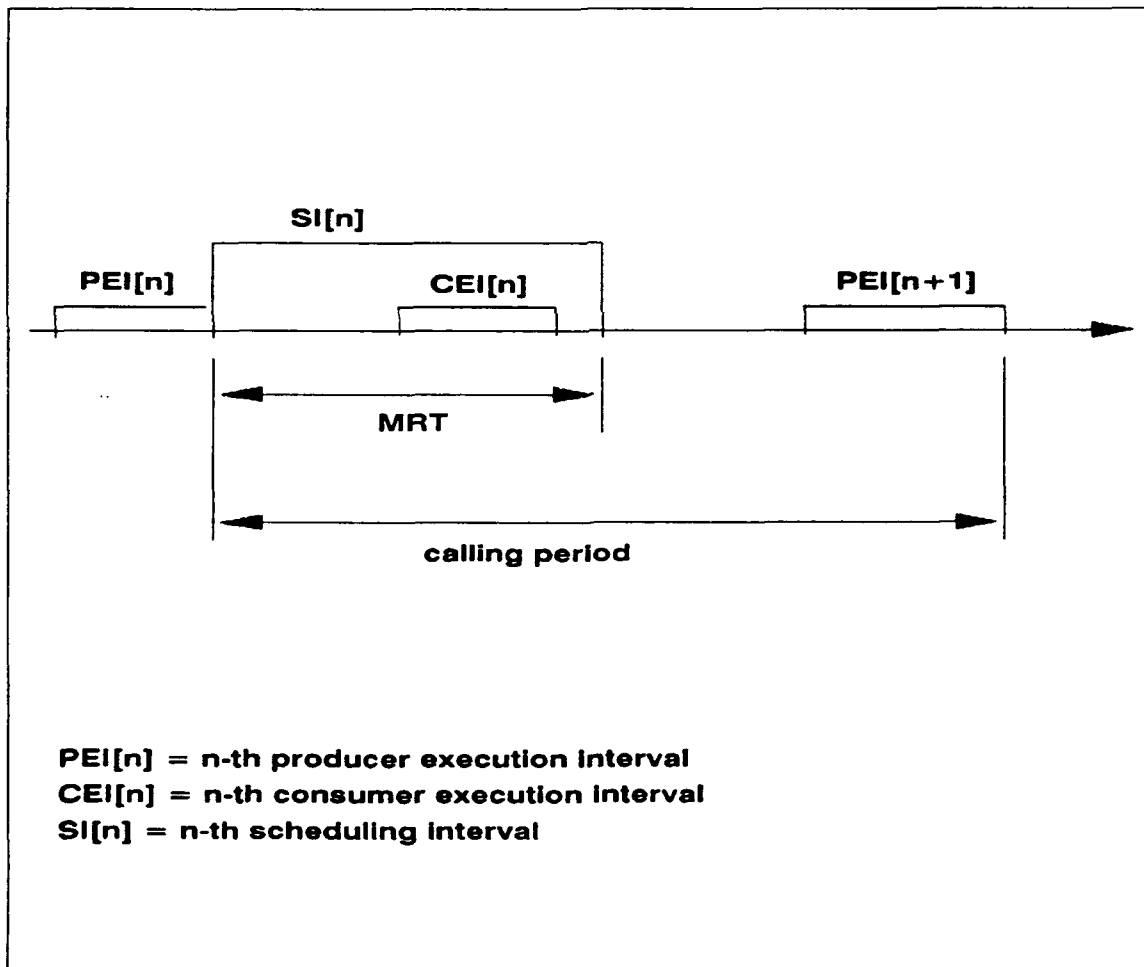


Fig. 4 Timing Constraints for a Periodic Operator

The static scheduler takes the length of each execution interval to be equal to the maximum execution time to allow for worst case conditions. If a time-critical operator completes before the end of the execution interval reserved for it by the static scheduler, the remaining time in the execution interval is used by the dynamic scheduler for the execution of a non time-critical operator. [Ref. 8:p. 5]

Operators triggered by the arrival of new data values are sporadic. Timing constraints for sporadic operators are optional. Sporadic operators with timing constraints must have both a **maximum response time (MRT)** and a **minimum calling period (MCP)** in addition to a MET. The MRT is an upper bound on the time between the arrival of a new data value and the time when the last value is put into the output streams of the operator in response to the arrival of the new data value. The MCP is a constraint on the environment of a sporadic operator, consisting of a lower bound on the delay between the arrival of one set of inputs and the arrival of the next set. The relation between these quantities is illustrated in Fig. 5.  $SI[n]$  denotes the  $n$ -th scheduling interval for the consumer operator,

which is sporadic and time-critical.  $CEI[n]$  denotes the  $n$ -th execution interval for the consumer operator, and  $PEI[n]$  denotes the  $n$ -th execution interval for the producer operator, which is assumed here to be time-critical also. The response time associated with a consumer operator is measured from the end of the execution interval for the



**Fig. 5 Timing Constraints for a Sporadic Operator**

producer operator of the triggering data value to the end of the execution interval for the consumer operator of the triggering data value. [Ref. 8:p. 6]

Unlike the MET, the MRT includes a scheduling delay. The MRT gives the length of the scheduling interval. The static scheduler may not be able to use the entire scheduling interval if the producer is non time-critical, because the ending time of the producer's execution interval is not known to the static scheduler in that case. [Ref. 8:p. 6]

The calling period of an operator is the length of time between the end of the execution interval for the producer of the triggering data value and the end of the execution interval for the producer of the next triggering data value. The calling period must not be less than the MCP. The MCP of an operator constrains the behavior of the producers of the triggering data values rather than constraining the behavior of the operator itself. An MCP constraint is needed to allow the realization of a maximum response time constraint with a fixed amount of computational resources, via a limit on the frequency with

which new data can arrive. Violation of an MCP constraint should result in a warning message. [Ref. 8:p. 6-7]

#### **d. Control Constraints**

The control aspect of a PSDL operator is specified implicitly, via control constraints. Control constraints are used for the following purposes:

- (1) Controlling operator execution.
- (2) Controlling output.
- (3) Controlling exceptions.
- (4) Controlling timers. [Ref. 8:p. 7]

Exceptions are discussed in Chapter IV. Readers interested in a discussion of timers can refer to [Ref. 11:pp. 18-20].

Control constraints controlling operator execution are called **triggering conditions**. The forms of PSDL triggering conditions are shown in Fig. 6. A triggering condition has two parts, the **trigger** and the **guard**, both of which are optional. The trigger defines the conditions under which an operator can be fired. The keywords "TRIGGERED BY ALL" indicate the operator is ready to fire whenever new data values have arrived on all of the input data streams named in the `id_list`. The `id_list` can contain any non-empty subset of the input data streams for the



operator. [Ref. 8:p. 7] This kind of trigger can be used to ensure that the output of the operator is always based on fresh data for all of the inputs in the list, and can be used to synchronize the processing of corresponding input values from a number of input streams [Ref. 6:p. 1414]. The natural dataflow firing rule corresponds to a "TRIGGERED BY ALL" triggering condition that lists all of the input data streams of the operator. [Ref. 8:p. 7-8]

```
triggering_condition =  
  "OPERATOR" id "TRIGGERED" ["BY" trigger] ["IF" guard]  
trigger = "ALL" id_list | "SOME" id_list
```

Fig. 6 PSDL Triggering Conditions

The keywords "TRIGGERED BY SOME" indicate the operator can be fired if there is a new data value on at least one of the data streams named in the id\_list [Ref. 8:p. 8]. This kind of trigger can be used to keep software estimates of sensor data up to date [Ref. 6:p. 1414]. A null trigger means that the operator can fire at any time, whether or not any new data values have arrived. Null triggers are most useful for periodic operators.

The triggering conditions of the operators implicitly determine the types of the data streams. A

stream is a dataflow stream if it appears in a "TRIGGERED BY ALL" constraint of the consumer operator and is a sampled stream otherwise. [Ref. 8:p. 8]

The second part of the triggering condition is the guard, a boolean expression which can depend only on the input values to the operator and locally available state information. A null guard is always true. When an operator fires, it reads one data value from each of its input streams. If the predicate is satisfied, then the output values of the operator are calculated, otherwise the firing of the operator terminates immediately without producing any output. [Ref. 8:p. 8]

Constraints for controlling output are based on output guards. An output guard is a boolean expression that can depend on the input data of the operator, locally available state information, and the calculated output values. A null output guard is always true. [Ref. 8:p. 8] An example of a control constraint specifying a conditional output is shown below.

OPERATOR t OUTPUT z IF  $1 < z$  AND  $z < \max$

The example shows an operator with an output guard, which depends on the input value MAX and the output value z [Ref. 6:p. 1415]. An output value is written to the output stream provided that the output guard evaluates to true. If the output guard evaluates to false, then nothing is written into the stream. [Ref. 8:p. 8]

## **2. Abstractions**

Abstractions are an important means for controlling complexity, which is especially important in rapid prototyping because a system must appear to be simple to be built or analyzed quickly. PSDL supports three kinds of abstractions: data abstractions, operator abstractions, and control abstractions. [Ref. 6:p. 1413]

### **a. Operator Abstractions**

There are two types of operator abstractions: functional abstractions and state machine abstractions. PSDL supports both types. A PSDL operator consists of two parts: a SPECIFICATION part and an IMPLEMENTATION part. The specification part contains attributes describing the form of the interface, the timing characteristics, and descriptions of the observable behavior of the operator.

The attributes both specify the operator and form the basis for retrievals from a software base. The set of attributes consists of GENERIC PARAMETERS, INPUT, OUTPUT, STATES, EXCEPTIONS, and TIMING INFORMATION. [Ref. 6:p. 1413]

A PSDL operator corresponds to a state machine abstraction if its specification part contains a STATES declaration, otherwise it corresponds to a functional abstraction. The STATES declaration gives the types of the state variables and also their initial values. [Ref. 6:p. 1413]

The implementation part of the operator signifies whether it is atomic or composite. Atomic operators have a keyword specifying the underlying programming language, followed by the name of the module implementing the operator. This name is filled in as the result of a successful retrieval from the software base, or is supplied by the designer in cases where the module cannot be constructed from reusable components and must be coded manually. [Ref. 6:p. 1413]

#### **b. Data Abstractions**

All of the PSDL data types are immutable. For

immutable types the set of instances and the properties of each instance are fixed. All PSDL variables are local. Both mutable data types and global variables can lead to coupling problems in large prototype systems and thus have been excluded from PSDL. [Ref. 6:p. 1413]

The PSDL data types include the immutable subset of the built-in types of Ada, user defined abstract types, the special types TIME and EXCEPTION, and the types that can be built using the immutable type constructors of PSDL. The PSDL type constructors (see Table 1) were chosen to provide powerful data modeling facilities. [Ref. 6:p. 1414]

TABLE 1. PSDL TYPE CONSTRUCTORS

<pre>set[item: type] sequence[item: type] map[from: type, to: type] tuple[tag_1: T_1,..., tag_n: T_n] one_of[tag_1: T_1,..., tag_n: T_n] relation[tag_1: T_1,..., tag_n: T_n]</pre>
---

Finite sets, sequences, and mappings correspond to the usual mathematical concepts. Tuples are finite Cartesian products, with operations for constructing tuples and for extracting components. One\_ofs are tagged disjoint unions of a finite number of other types, with operations for constructing one\_of values with a given tag

(injections), for testing whether a one\_of value has a given tag (domain predicates), and for extracting the data component of a one\_of (projections). Relations are n-ary mathematical relations, with operations that are commonly used in relational databases (select, project, join, union, set difference, etc.). [Ref. 6:p. 1414]

### **c. Control Abstractions**

Enhanced data flow diagrams, augmented by control constraints represent the control abstractions of PSDL. Periodic execution is supported explicitly, as well as concurrent execution in certain cases. Order of execution is determined from the data flow relations given in the enhanced data flow diagrams, based on the rule that an operator consuming a data value must not start until after the operator producing the data value has completed. This applies to periodic operators only at synchronization points, which occur at intervals equal to the least common multiple of the periods of the two operators.

## **B. THE PROTOTYPING METHOD**

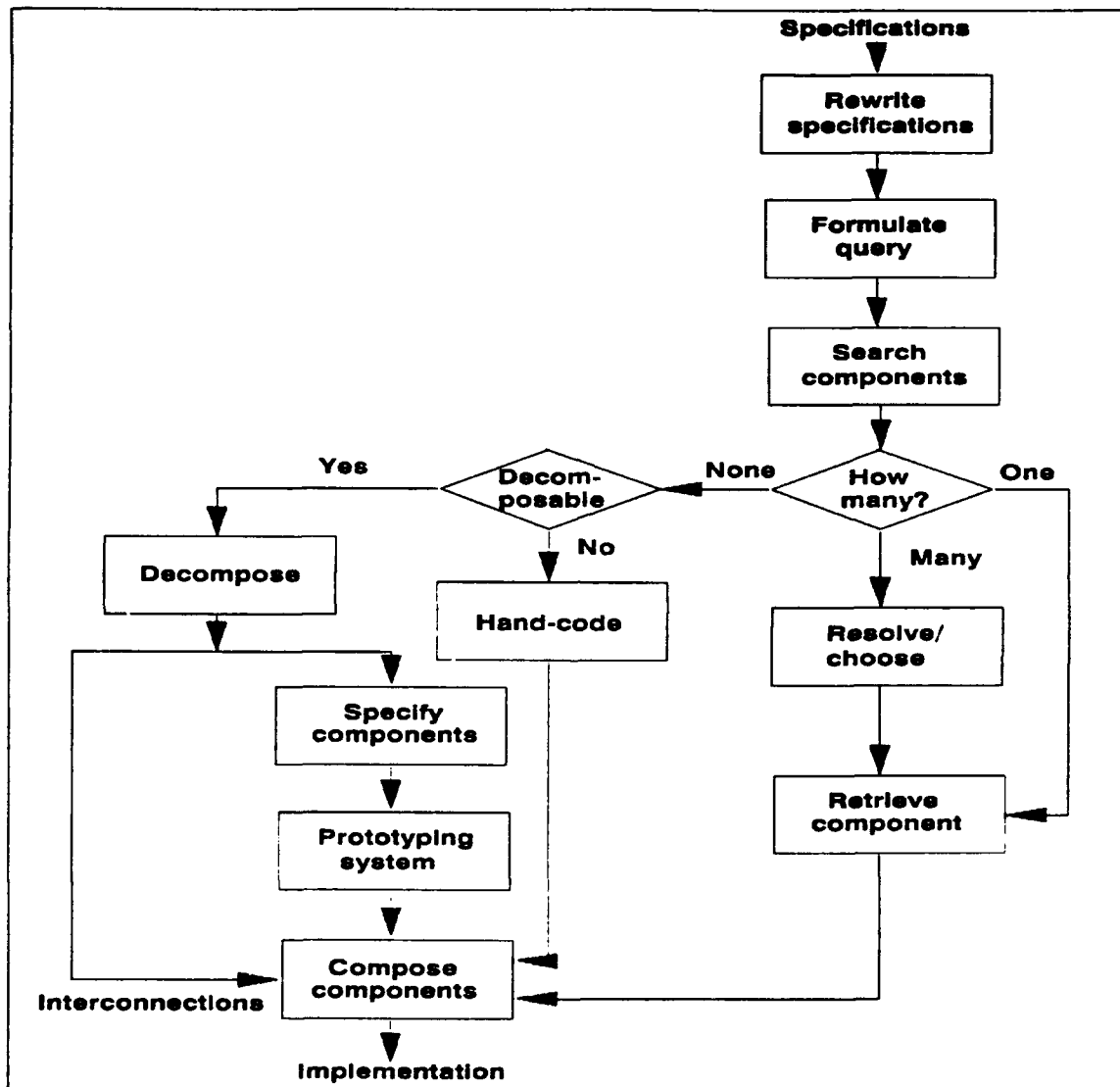
The PSDL prototyping method is a decomposition strategy which results in a hierarchically structured prototype. The

prototyping method provides a strategy for filling in more details at any level of the prototype design and helps the designer focus on the critical subsystems that must be refined to resolve the problems that motivated the rapid prototyping effort. [Ref. 9:p. 26]

Fig. 7 illustrates the major steps in the prototyping method. The designer begins by entering the specifications of the intended software component. A rewrite subsystem maps the specification into an internal abstract form that is used by the design-management system to search for a reusable component to implement the specification. If a reusable component is found, the design-management system retrieves it; if it finds several reusable components that meet the specification, the designer must choose one. Otherwise, the specification cannot be met by an existing component and the designer should decompose the specification into simpler specifications or create a hand-coded implementation if the component is so simple that decomposition does not make sense. [Ref. 7:p. 67]

When a specification is decomposed into a network of simpler components, the required interconnections are

recorded in the design database with a dataflow diagram. This helps serve as design documentation. After the designer decomposes the specification into simpler



**Fig. 7 The Prototyping Method**

specifications, the entire prototyping method is then applied to those specifications. [Ref. 7:p. 67]

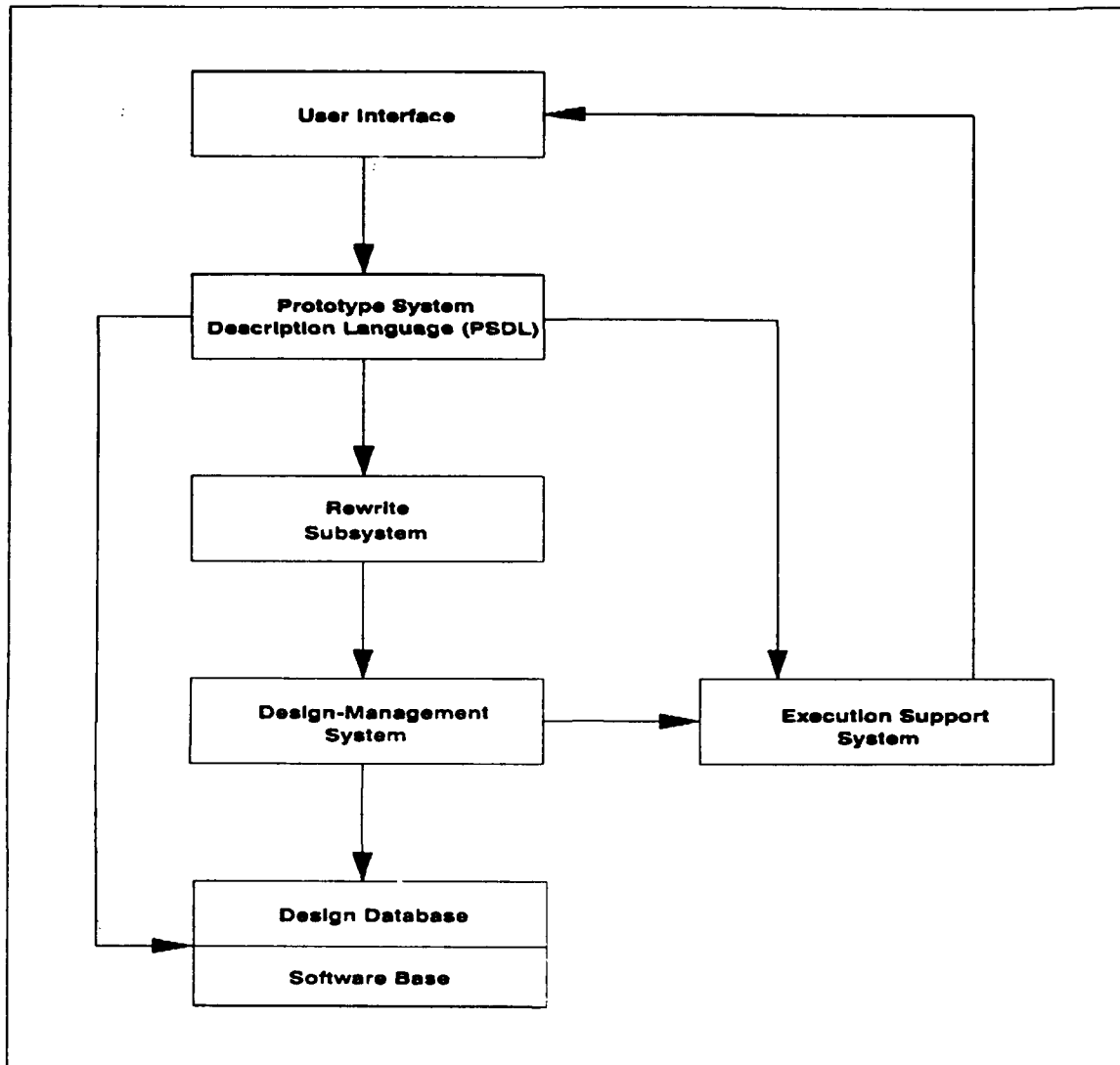


### **III. COMPUTER-AIDED PROTOTYPING SYSTEM**

The computer-aided prototyping system (CAPS) is a set of software tools which reduces the designer's efforts by automating time-consuming tasks in conventional prototyping, such as turning specifications into prototypes, modifying prototypes, and searching for available reusable components [Ref. 7:p. 67-68]. Designed to operate on the prototyping language PSDL, CAPS consists of a syntax-directed editor with graphics capabilities, a rewrite system, a design-management system, a software base, a design database, and an execution support system [Ref. 7:p. 66]. Fig. 8 shows the architecture of the computer-aided prototyping system. Following is a short description of the functions of each of the components of CAPS.

#### **A. USER INTERFACE**

The user interface consists of a syntax-directed editor for PSDL and a graphics tool to construct and display dataflow diagrams. The syntax-directed editor expedites the designer's data entry at a terminal by eliminating syntax errors, automatically supplying keywords, and prompting



**Fig. 8 CAPS System Architecture**

with a choice of legal syntactic alternatives at each point.

[Ref. 9:p. 29]

The graphics tool provides a graphical view of the enhanced data flow diagram in the PSDL implementation of a composite module. It helps you visualize the relationships between the components of a decomposition through a two-

dimensional dataflow diagram and provides a convenient way to enter and update the decomposition information in the dataflow diagram. [Ref. 9:p. 29]

## B. REWRITE SYSTEM

The rewrite system translates semantically equivalent specifications into a common (normalized) form that is used by the design-management system to search for components. Normalized components are easier to retrieve because there are fewer keys to search for in the software base. This is a more practical approach than trying to generate all variations of a description and searching the software base for each variation. Table 2 shows an example of an informal rewriting system. [Ref. 7:p. 69]

TABLE 2.  
SAMPLE REWRITE-SYSTEM RULE TABLE.

Term	Aliases
update	change, modify, refresh, replace, substitute
read	fetch, obtain, input, get, retrieve

The rewrite system would replace all occurrences of the aliases by the associated basic terms. The sentence "Fetch the order from the transaction file and modify the

inventory" would be rewritten to "Read the order from the transaction file and update the inventory." [Ref. 7:p. 69]

### **C. DESIGN-MANAGEMENT SYSTEM**

The design-management system is responsible for organizing, retrieving, and instantiating reusable components from the software base and for managing the versions, refinements, and alternatives of the prototypes in the design database. The design-management system is essentially a database-management system that can efficiently manage long transactions, data describing complex objects (such as software components), the iterative and tentative nature of the design process that leads to versions, refinements, and alternatives of the design objects, and concurrent design operations in a distributed computing environment. It also provides special-purpose operations to compose components, and a browsing capability similar to the one provided by the Smalltalk environment. [Ref. 7:p. 69]

### **D. SOFTWARE BASE**

The software base consists of PSDL descriptions and code

for all available reusable software components. Each component in the software base must have a PSDL specification. This PSDL specification is organized as a set of distinct but related attributes. The design-management system provides component retrieval based on partial matches of these attributes. The software base contains a relatively complete set of general-purpose components to perform the functions common to many systems, such as managing displays, sorting and searching, parsing input strings, and managing look-up tables. [Ref. 9:p. 29]

#### **E. DESIGN DATABASE**

The design database in the prototyping environment contains the PSDL prototype descriptions for each software development project using CAPS. This design history consists of the relationship between each version of the requirements and the corresponding versions of parts of the prototype. This information is useful in cases where parts of the requirements are returned to previous configurations, because it enables the system to help restore the corresponding parts of the prototype to their previous configurations. The design database will support retrievals

of the form

- given a requirement, find all the PSDL components that implement it, or

- given a PSDL component, find all the requirements it implements. [Ref. 9:p. 29]

#### **F. EXECUTION SUPPORT SYSTEM**

Within the CAPS architecture there exists an execution support system which allows the designer to execute the prototype. This support system consists of three major components: a translator, a static scheduler, and a dynamic scheduler. The translator generates code binding together the reusable components extracted from the software base. Its main functions are to implement data streams and control constraints. The static scheduler allocates time slots for operators with real-time constraints before execution begins. If the allocation succeeds, all operators are guaranteed to meet their deadlines even with worst-case execution times. The dynamic scheduler invokes operators without real-time constraints in the time slots not used by the operators with real-time constraints as execution proceeds. [Ref. 5:p. 16] [Ref. 10:p. 15-16]

The execution support system is covered extensively in the remaining chapters.

#### IV. INTEGRATION OF THE EXECUTION SUPPORT SYSTEM

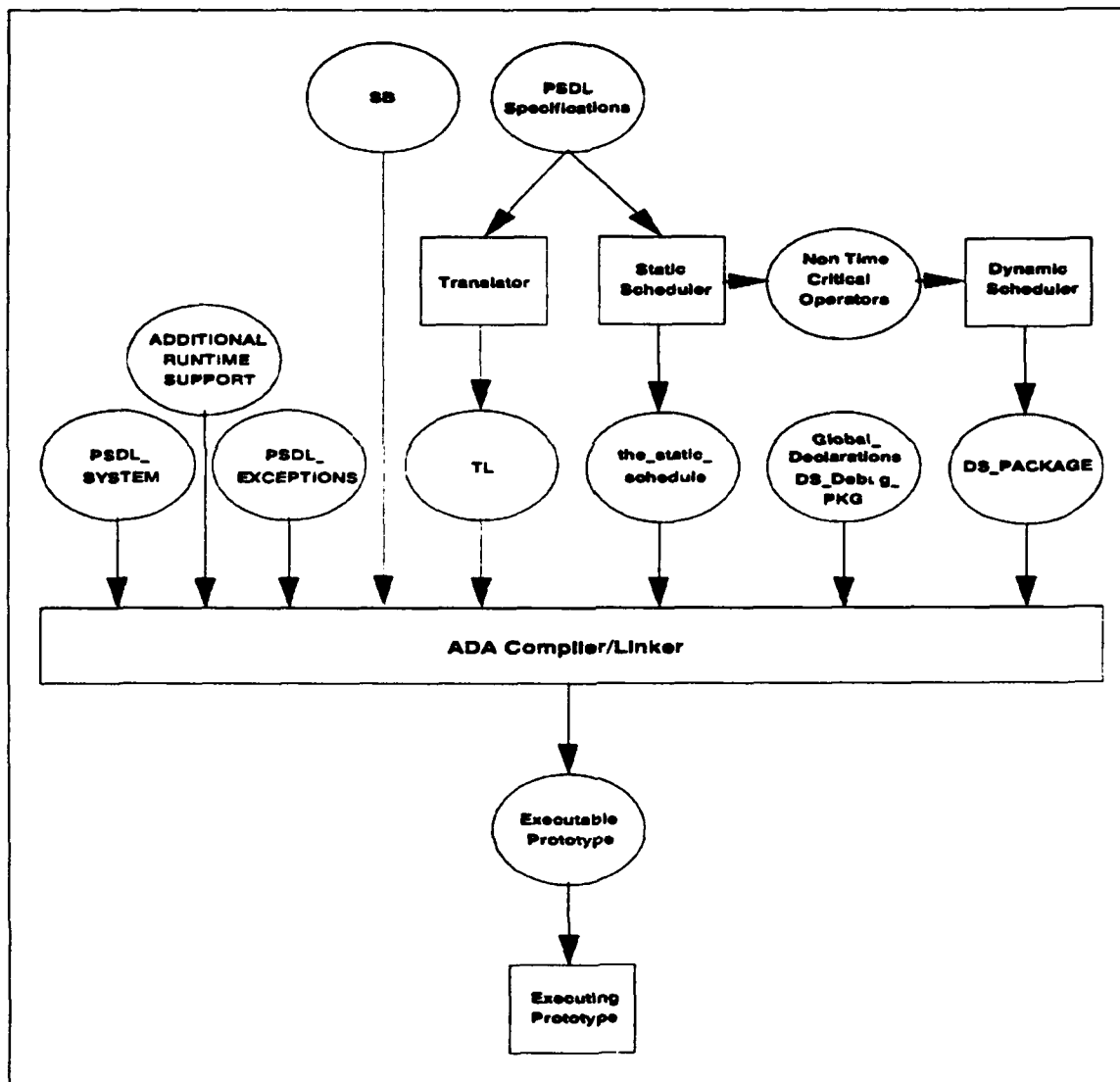
##### A. OVERVIEW

The execution support system as conceptualized by this author is shown in Fig. 9. It consists of three processes: the translator, the static scheduler and the dynamic scheduler. The translator takes as input the PSDL source code generated by the designer and produces DRIVER procedures, contained in package TL, which call the reusable components in package SB. The static scheduler takes as input the PSDL source code and produces two outputs: the static schedule for the time-critical operators and a file called `non_crits` containing the names of the non-time-critical operators. The dynamic scheduler takes as input the file `non_crits` and uses this to produce an Ada task containing procedure calls for the non-time-critical operators.

The user interface is responsible for invoking the translator, static scheduler and dynamic scheduler. The translator and the static scheduler can operate in parallel, however the dynamic scheduler must wait for completion of



the static scheduler before it can run. Once the translator, static scheduler and dynamic scheduler have completed, the user interface takes their outputs as well as the packages: PSDL\_SYSTEM, PSDL\_EXCEPTIONS, SB, Global\_Declarations, DS\_Debug\_PKG, TIMERS, VSTRINGS, List\_Single\_



**Fig. 9 Execution Support System**

Unbounded\_Unmanaged and PRIORITY\_DEFINITIONS and compiles and links them, thus forming the executable prototype. Note, the latter four packages are the ADDITIONAL RUNTIME SUPPORT.

Previous research resulted in separate implementations for the translator [Ref. 11], static scheduler [Ref. 12] [Ref. 13] [Ref. 14] [Ref. 15], and dynamic scheduler [Ref. 16]. These individual components were not previously integrated though into a functioning execution support system which enables the execution of prototypes written in PSDL. It is the development of this tool that is the focus of this thesis.

## **B. MODIFICATIONS TO THE TRANSLATOR**

### **1. Data Stream Implementation**

Data streams are the means by which PSDL operators communicate. A data stream is a communication link connecting exactly one producer operator to exactly one consumer operator. Altizer [Ref. 11:p. 40] describes an implementation for data streams in which data streams are implemented as an Ada generic package containing an embedded task. Inside the task are the various operations necessary

to support data triggers and data stream reads and writes. Four separate packages are provided to implement the variations of data streams. All of these packages are then grouped into a package called PSDL\_SYSTEM.

While Altizer's handling of data streams was found to be essentially adequate, several modifications were made to the original design. Appendix A contains the new version of PSDL\_SYSTEM.

One change made was to replace the literal value in the pragma PRIORITY with the constant BUFFER\_PRIORITY. The value of BUFFER\_PRIORITY is declared in the package PRIORITY\_DEFINITIONS along with the values of the constants STATIC\_SCHEDULE\_PRIORITY and DYNAMIC\_SCHEDULE\_PRIORITY. The purpose of doing this is to consolidate all the PRIORITY pragma values for the prototype into one package, so that future design changes and enhancements will be easier to make.

Another change made to the original design was to eliminate the record type DATA\_STREAM\_TOKEN. DATA\_STREAM\_TOKEN was determined to be unnecessary and was replaced instead with two local variables: BUFFER and FRESH.

The names of several identifiers in PSDL\_SYSTEM were changed. For instance, SAMPLED\_STREAM was changed to SAMPLED\_BUFFER. DATA\_STREAM was changed to BUFFER. GET was changed to READ. PUT was changed to WRITE, etc. This was done in the interest of improving clarity.

Finally, probably the most significant change made was to consolidate the generic packages SAMPLED\_STATE\_VAR and DATAFLOW\_STATE\_VAR into one package STATE\_VARIABLE. Having both SAMPLED\_STATE\_VAR and DATAFLOW\_STATE\_VAR was found to be redundant.

## **2. Integration of Reusable Components**

In Chapter II. of this thesis, a short description is given of the prototyping method, which is the process by which a PSDL atomic operator specification is used to extract a reusable Ada component from the software base. These components, which represent the implementations of the atomic operators, are critical to the functioning of the prototype. Yet, up until Altizer [Ref. 11:p. 38], no provision was made for their insertion into the prototype.

Altizer proposed that when a reusable module is extracted from the software base, that it be inserted into

the PSDL source code at the IMPLEMENTATION statement. Then, when the PSDL source code is processed by the translator this component would be extracted and placed in the TL package, which is the output of the translator.

This approach, though it seems viable, was never actually implemented by Altizer. An alternative approach that actually was implemented during the course of this thesis, makes use of the Ada `with` and `use` clauses. In this approach all components extracted from the software base are assembled into a package called SB which is placed into a file called sb.a. The output of the translator, package TL, consists then of DRIVER procedures which call these components. Visibility to package SB is provided via the Ada `with` and `use` clauses. This is illustrated in Fig. 10.

### 3. Exception Handling

PSDL exceptions are described by Luqi in [Ref. 17] as special data types that may be written to any data stream regardless of the stream's normal data type. When a PSDL exception is raised in an operator it is immediately output onto all of the operator's output data streams. All operators immediately downstream from this operator receive

the exception on one or more of their input streams and are then responsible for its handling.

```

with TEXT_IO; use TEXT_IO;
with PSDL_EXCEPTIONS; use PSDL_EXCEPTIONS;
package SB is
    .
    .
    .
end SB;

package body SB is
    .
    .
    .
    reusable Ada components
    .
    .
    .
end SB;

package TL is
    .
    .
    .
end TL;

with PSDL_SYSTEM; use PSDL_SYSTEM;
with PSDL_EXCEPTIONS; use PSDL_EXCEPTIONS;
with SB; use SB;
package body TL is
    .
    .
    .
    instantiations of data streams
    .
    .
    .
    DRIVER procedures
    .
    .
    .
end TL;

```

Fig. 10 Integration of Reusable Components

Altizer in [Ref. 11] describes an alternative method for handling PSDL exceptions. In his approach, a distinction is made between streams which carry normal data

values and streams which carry PSDL exceptions. Streams which carry PSDL exceptions are of type PSDL\_EXCEPTION and must be declared explicitly by an operator. An operator allowed to raise a PSDL exception can only communicate that exception to operators which are directly connected to it via an exception data stream. An operator receiving the PSDL exception on its input data stream is then by definition an exception handler.

While Altizer's method was determined to be easier to implement than the method originally proposed by Luqi, it was also determined to be inadequate. The approach to exception handling eventually decided upon in this thesis draws on this approach but differs somewhat. The following paragraphs will describe an example of a PSDL to Ada translation involving PSDL exceptions. At that time the method adopted in this thesis should become clear. Deviations from previous research in both method and implementation will be noted.

Appendix B contains a sample prototype which performs no particular function. The example consists of an enhanced data flow diagram, a prototype description, parts of its Ada

implementation and a supporting Ada package. Operator C1 is a composite operator. OP1, OP2 and OP3 are atomic operators. OP1, OP2 and OP3 are subcomponents of C1. Operator EXCEPTION\_HANDLER is an atomic operator. Its purpose is to handle any exceptions raised by OP1. The data streams visible in this diagram are A, B and EXCP. A and B are data streams of normal data types. EXCP is an exception data stream. It is of type PSDL\_EXCEPTION.

Referring to Section B of Appendix B, it can be seen that data streams A and B are declared to be of type INTEGER. Data stream EXCP is declared to be of type PSDL\_EXCEPTION. The statement

EXCEPTION OUT\_OF\_RANGE IF A > 100

is a PSDL EXCEPTION statement. It is interpreted as "If the value which is to be output to A is greater than 100, then output the PSDL exception OUT\_OF\_RANGE onto all of the operator's output data streams declared to be of the PSDL\_EXCEPTION data type. Do not output the calculated value onto A." This represents a departure from previous research. Prior to this thesis, the syntax of the EXCEPTION statement required that a target data stream be specified.



In the interest of efficiency, it was decided that the default be all data streams of type PSDL\_EXCEPTION and that if the designer wished to suppress outputting the exception to any particular stream he could do so via an Output Condition [Ref. 6:p. 1415-1416].

The statement

TRIGGERED BY ALL EXCP IF EXCP = OUT\_OF\_RANGE

represents another departure from previous research. It is a PSDL triggering condition which is interpreted here as "If there is a new data value on input data stream EXCP, then consume the data value. If the value consumed equals the PSDL exception OUT\_OF\_RANGE, then allow the operator EXCEPTION\_HANDLER to execute. If the expression EXCP = OUT\_OF\_RANGE is not satisfied, then EXCEPTION\_HANDLER is not allowed to execute any farther and is terminated." Altizer introduced a special operation in his thesis to perform the above function, which is to determine if a particular exception has been raised. This was determined to be unnecessary. A special note here. In the above statement, the condition EXCP = OUT\_OF\_RANGE is optional. If this condition is null, then the presence of any PSDL exception

on EXCP will cause EXCEPTION\_HANDLER to execute.

One last item of interest in Section B of Appendix B is the statement

#### EXCEPTIONS NEGATIVE\_NUMBER

This statement is interpreted as "During the execution of operator OP1, its possible for an Ada exception NEGATIVE\_NUMBER to be raised. If this happens convert NEGATIVE\_NUMBER into a PSDL exception and output it onto all data streams of type PSDL\_EXCEPTION, which in this case is only one stream, EXCP." This provides a mechanism for interfacing between Ada exceptions and PSDL exception handlers. Ada exceptions that are not declared in the PSDL specifications are treated as errors and cause abnormal termination of the prototype.

Section C of Appendix B is a partial Ada implementation of the prototype described in Section B. It consists of two packages: TL and SB. Package SB is as described earlier in this thesis. It is a package containing the reusable components extracted from the software base. Package TL is the output of the translator. It consists of DRIVER procedures which call the components in SB.

In both package TL and package SB visibility is established to a package PSDL\_EXCEPTIONS via the Ada **with** and **use** clauses,

with PSDL\_EXCEPTIONS; use PSDL\_EXCEPTIONS;

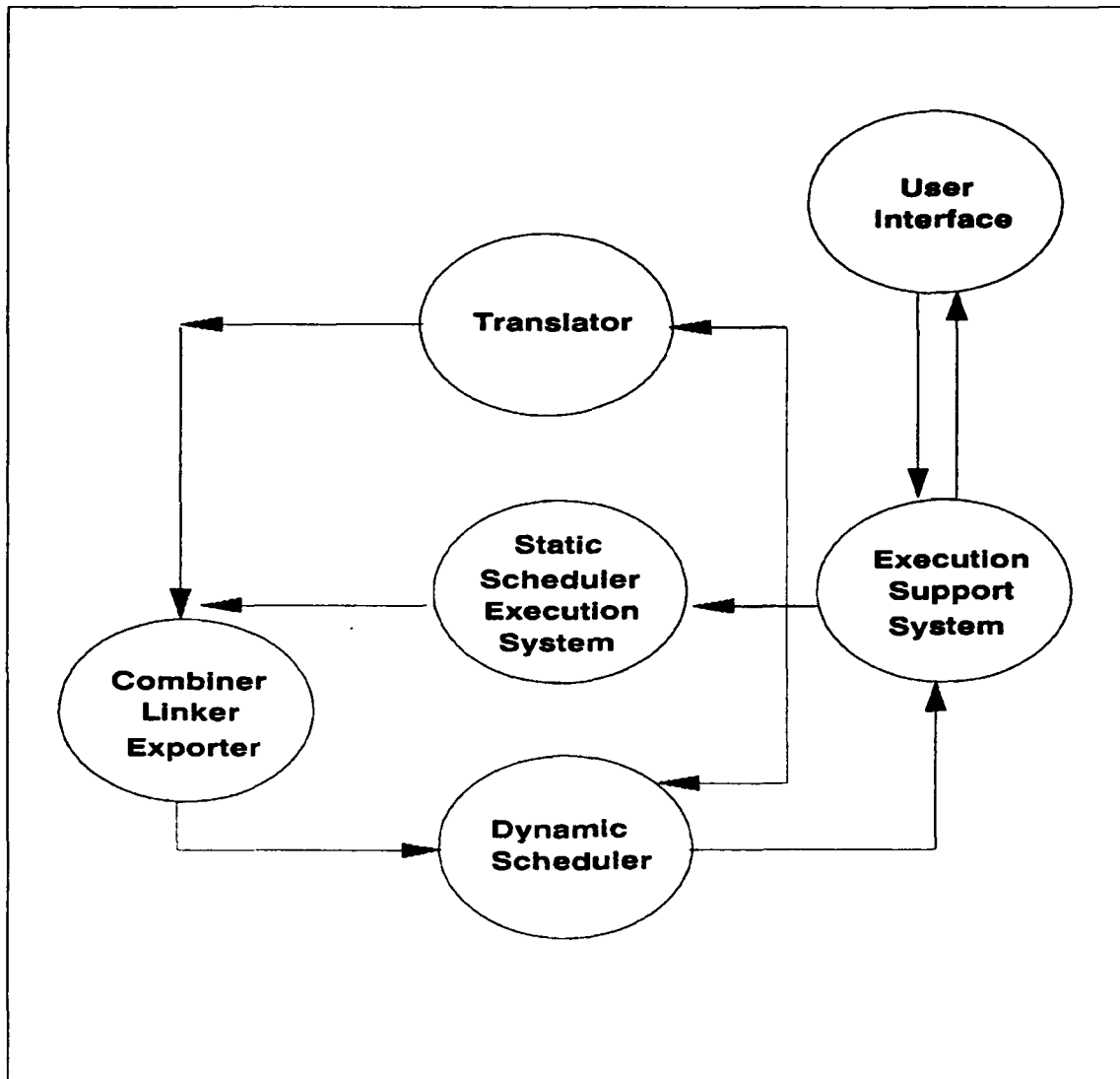
Package PSDL\_EXCEPTIONS is an Abstract Data Type (ADT). Its purpose is to define the type PSDL\_EXCEPTION and various operations applicable to objects of the type. When the reusable components were placed into a separate package SB, it was found necessary to abstract out the type PSDL\_EXCEPTION and to create the ADT. PSDL\_EXCEPTIONS is listed in Section D of Appendix B.

### **C. IMPLEMENTATION OF THE DYNAMIC SCHEDULER**

As stated at the beginning of this chapter, the execution support system consists of three major components: a translator, a static scheduler and a dynamic scheduler. Previous research resulted in implementations for these components, but they were never integrated into a functioning execution support system which enables the execution of prototypes written in PSDL. Providing this tool is the purpose of this thesis.

In the case of the translator, Altizer [Ref. 11] provided an implementation which when modified as described earlier, was assimilated into the execution support environment. In the case of the static scheduler, Kilic [Ref. 15] provided an implementation which when modified was assimilated into the execution support environment. Not so with the dynamic scheduler though.

The dynamic scheduler as implemented by Wood [Ref. 16] presented a problem. The problem is that Wood's dynamic scheduler is based on a conceptualization of the execution support system which differs from the one adopted in this thesis. As envisioned by Wood, Fig. 11, the translator is a separate process which can execute in parallel with the static scheduler. The static scheduler is part of a system containing the static scheduler, its debugging system, and the process by which the non-time critical operators are transformed into executable code. The dynamic scheduler coordinates the execution of the critical and non-critical operators. It and its debugging system form another distinct part of the execution support system.



**Fig. 11 Execution Support System, Previous**

According to Wood, the translator and the static scheduler produce three outputs: the executable code for the operators, the static schedule for the time-critical operators, and the listing of procedure calls for the non-time-critical operators. These outputs must be compiled and linked together before the dynamic scheduler can be invoked.

The user interface in CAPS is responsible for invoking the static scheduler, the translator, and the dynamic scheduler. The user interface also ensures that the outputs above are compiled and linked before invoking the dynamic scheduler.

Owing to the incompatibility between Wood's conceptualization and the one in this thesis, it was necessary then to come up with a new implementation for the dynamic scheduler. This is presented in Appendix C. As can be seen, the dynamic scheduler was implemented as a procedure. It has one input and one output. Input consists of the names of the non-time-critical operators. Output consists of a task containing procedure calls to the non-time-critical operator DRIVERS in package TL. Visibility to TL, as well as to the package PRIORITY\_DEFINITIONS, is provided via the Ada `with` and `use` clauses. The output of the dynamic scheduler is referred to as a dynamic schedule in this thesis. Fig. 12 is an example schedule.

One item to take note of in the sample schedule is the statement

```
pragma priority (DYNAMIC_SCHEDULE_PRIORITY);
```

```

with TL; use TL;
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS
package DS_PACKAGE is
  task DYNAMIC_SCHEDULE is
    pragma priority (DYNAMIC_SCHEDULE_PRIORITY);
  end DYNAMIC_SCHEDULE;
end DS_PACKAGE;

package body DS_PACKAGE is
  task body DYNAMIC_SCHEDULE is
  begin
    loop
      non_critical_op1_DRIVER;
      non_critical_op2_DRIVER;
      null;
    end loop;
  end DYNAMIC_SCHEDULE;
end DS_PACKAGE;

```

Fig. 12 Sample Dynamic Schedule

A pragma is a directive to the Ada compiler. The priority pragma specifies the priority of a task or main program. It takes as a single argument either an integer or an expression which evaluates to an integer. A task with a higher priority will execute before a task with a lower priority.

The static schedule is a task which contains procedure calls to the time-critical operator DRIVERS in TL. It too has a priority pragma statement. The pragma statements in the dynamic and static schedules are set so that the static schedule always has the higher priority. This is to ensure that when the static schedule needs the processor it will get it. The use of Ada's tasking facilities to control

operator execution is a feature which originally appeared in Wood's implementation. Though as mentioned above, the dynamic scheduler implementations are different, this was a feature that was found to be especially useful and thus was incorporated here.

#### **D. MODIFICATIONS TO THE STATIC SCHEDULER**

Integration into the execution support system of the static scheduler Kilic [Ref. 15] presented few problems for this author. Test cases run through the scheduler during integration identified only a single minor error in the actual functioning of the scheduler; this was quickly corrected. Subsequent modifications during integration consisted entirely of changes of an interface nature. These are described below.

Fig. 13 is a sample static schedule. When Kilic was implementing the static scheduler, the work of integrating the debugger into the execution support system was still in its infancy. Static schedules created by the static scheduler consequently contained no reference to the debugger. This was changed. Added to static schedules now are the statements



```
with GLOBAL_DECLARATIONS; use GLOBAL_DECLARATIONS;  
with DS_DEBUG_PKG; use DS_DEBUG_PKG;
```

which establish visibility to the debugger and the statement

```
DS_DEBUG.RUNTIME_MET_FAILURE (  
  VARSTRING.VSTR("CRITICAL_OP3"),  
  CURRENT_TIME, CRITICAL_OP3_STOP_TIME3,  
  PERIOD);
```

which executes an entry call to Runtime\_MET\_Failure. The actual functioning of the debugger is described in the next section and will not be covered here.

One item that does need to be covered here though is the use of the Ada delay statement in the static schedule. It was mentioned in the previous section that priority pragma statements are utilized in the dynamic and static schedules to ensure that when the static schedule needs the processor it gets it. The question now is "How does the dynamic schedule get the processor then?" The answer is via the Ada delay statement.

The delay statement is used in Ada to suspend execution of a task or main body. When a time-critical operator completes execution a check is made to determine if the operator's scheduled stop time is greater than the current time. If it is, then the static schedule delays for the

time remaining till its stop time. Once it does this, it effectively gives up the processor to the dynamic schedule. When the length of the delay is over, the static schedule is given the processor back.

```

with GLOBAL_DECLARATIONS; use GLOBAL_DECLARATIONS;
with DS_DEBUG_PKG; use DS_DEBUG_PKG;
with TL; use TL;
with DS_PACKAGE; use DS_PACKAGE;
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS;
with CALENDAR; use CALENDAR;
with TEXT_IO; use TEXT_IO;
procedure STATIC_SCHEDULE is
  CRITICAL_OP3_TIMING_ERROR : exception;
  CRITICAL_OP2_TIMING_ERROR : exception;
  CRITICAL_OP1_TIMING_ERROR : exception;
  task SCHEDULE is
    pragma priority (STATIC_SCHEDULE_PRIORITY);
  end SCHEDULE;

  task body SCHEDULE is
    .
    .
    .
begin
  loop
    begin
      CRITICAL_OP1_DRIVER;
      SLACK_TIME := START_OF_PERIOD + CRITICAL_OP1_STOP_TIME1 - CLOCK;
      if SLACK_TIME >= 0.0 then
        delay (SLACK_TIME);
      else
        raise CRITICAL_OP1_TIMING_ERROR;
      end if;
      delay (START_OF_PERIOD + CRITICAL_OP1_STOP_TIME1 - CLOCK);

      CRITICAL_OP2_DRIVER;
      .
      .
      .
      delay (START_OF_PERIOD + CRITICAL_OP2_STOP_TIME2 - CLOCK);

      CRITICAL_OP3_DRIVER;
      .
      .
      .
      START_OF_PERIOD := START_OF_PERIOD + PERIOD;
      delay (START_OF_PERIOD - clock);
    end
  end loop
end;

```

Fig. 13 Sample Static Schedule

```

exception
  when CRITICAL_OP3_TIMING_ERROR =>
    PUT_LINE("timing error from operator CRITICAL_OP3");
    CURRENT_TIME:= clock - START_OF_PERIOD;
    DS_DEBUG.RUNTIME_MET_FAILURE (
      VARSTRING.VSTR("CRITICAL_OP3"),
      CURRENT_TIME, CRITICAL_OP3_STOP_TIME3, PERIOD);
    START_OF_PERIOD := clock;
  when CRITICAL_OP2_TIMING_ERROR =>
    .
    .
    .
  when CRITICAL_OP1_TIMING_ERROR =>
    .
    .
    .
end;
end loop
end SCHEDULE;

begin
  null;
end STATIC_SCHEDULE;

```

Fig. 13 Continued

## E. THE DEBUGGER

### 1. Background

There are three kinds of exceptions defined in this thesis: Ada exceptions not declared in the prototype description, PSDL exceptions defined by the prototype designer to include Ada exceptions declared in the prototype description and Ada exceptions declared by the PSDL runtime system. Ada exceptions not declared in the prototype description include the predefined exceptions declared in package STANDARD. The raising of this type of exception during prototype execution results in abnormal termination.

PSDL exceptions defined by the prototype designer were discussed in section B of this chapter. Handling of these exceptions is by the exception handler which the designer must provide in package SB. Ada exceptions declared by the PSDL runtime system, of which there are three, are CAPS specific exceptions which can occur during the execution of any prototype. They are: BUFFER\_UNDERFLOW, BUFFER\_OVERFLOW and OPERATOR\_TIMING\_ERROR, where OPERATOR is the name that was given to the operator in the prototype description. Exception BUFFER\_UNDERFLOW is raised when an operator attempts to read from an empty data stream. Exception BUFFER\_OVERFLOW is raised when an operator attempts to write to a dataflow stream which currently contains a value. Exception OPERATOR\_TIMING\_ERROR is raised when an operator exceeds its MET. Ada exceptions declared by the PSDL runtime system are handled by the debugger which is described below.

As part of the earlier research effort on CAPS, in addition to developing the translator, the static scheduler and the dynamic scheduler, work was also expended on the development of a runtime debugger for the execution support

system. This work was done primarily by Wood and is described in her thesis [Ref. 16]. Wood calls her debugger the Dynamic Scheduler debugging system and implements it as a task consisting of six entries. They are: Runtime\_MET\_Failure, Buffer\_Underflow, Buffer\_Overflow, Exception\_Error, Non\_Time\_Critical\_Operators\_Done and Static\_Schedule\_Done. The first four entries were provided to serve as handlers for the Ada exceptions declared by the PSDL runtime system. The latter two entries were provided to allow for graceful termination of the prototype.

During the course of integrating Wood's debugging system into the execution support system, entry Exception\_Error was determined to be unnecessary and was eliminated. Entries Non\_Time\_Critical\_Operators\_Done and Static\_Schedule\_Done were determined to be predicated on the false assumption that all the operators execute only once and likewise were eliminated. Thus the modified version of the Dynamic Scheduler debugging system called simply the debugger in this thesis, consists of only three entry statements. The code is included as Appendix D.

## 2. Sample Session

The purpose of any debugger is usually a twofold one-to identify errors and if possible, to correct them. The purpose of this debugger is no different. In the case of `Buffer_Underflow` and `Buffer_Overflow`, the function performed is one of identification-a message is printed to a file, the prototype terminates. In the case of `Runtime_MET_Failure` though, the function performed is not only one of identification, but also one of correction.

Reference is made to Fig. 14 which is repeated from the previous section. When a critical operator exceeds its MET during prototype execution, a `TIMING_ERROR` exception is raised. At this point, control passes to the exception handler, an error message is printed to the screen and an entry call is made to `Runtime_MET_Failure`. Prototype execution has in effect been suspended. Reference is now made to Appendix D. Upon accepting the entry, the first action the debugger takes is to determine if the operator which exceeded its MET is in the `Operators_Overrun` list. The `Operators_Overrun` list is a list of records where each record contains the name of an operator that has exceeded its MET and a count of the number of times it has done so.

```

with GLOBAL_DECLARATIONS; use GLOBAL_DECLARATIONS;
with DS_DEBUG_PKG; use DS_DEBUG_PKG;
with TL; use TL;
with DS_PACKAGE; use DS_PACKAGE;
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS;
with CALENDAR; use CALENDAR;
with TEXT_IO; use TEXT_IO;
procedure STATIC_SCHEDULE is
  CRITICAL_OP3_TIMING_ERROR : exception;
  CRITICAL_OP2_TIMING_ERROR : exception;
  CRITICAL_OP1_TIMING_ERROR : exception;
  task SCHEDULE is
    pragma priority (STATIC_SCHEDULE_PRIORITY);
  end SCHEDULE;

  task body SCHEDULE is
    .
    .
    .
begin
  loop
    begin
      CRITICAL_OP1_DRIVER;
      SLACK_TIME:= START_OF_PERIOD + CRITICAL_OP1_STOP_TIME1 - CLOCK;
      if SLACK_TIME >= 0.0 then
        delay (SLACK_TIME);
      else
        raise CRITICAL_OP1_TIMING_ERROR;
      end if;
      delay (START_OF_PERIOD + CRITICAL_OP1_STOP_TIME1 - CLOCK);

      CRITICAL_OP2_DRIVER;
      .
      .
      .
      delay (START_OF_PERIOD + CRITICAL_OP2_STOP_TIME2 - CLOCK);

      CRITICAL_OP3_DRIVER;
      .
      .
      .
      START_OF_PERIOD := START_OF_PERIOD + PERIOD;
      delay (START_OF_PERIOD - clock);
    exception
      when CRITICAL_OP3_TIMING_ERROR =>
        PUT_LINE("timing error from operator CRITICAL_OP3");
        CURRENT_TIME:= clock - START_OF_PERIOD;
        DS_DEBUG.RUNTIME_MET_FAILURE (
          VARSTRING.VSTR("CRITICAL_OP3"),
          CURRENT_TIME, CRITICAL_OP3_STOP_TIME3, PERIOD);
        START_OF_PERIOD := clock;
      when CRITICAL_OP2_TIMING_ERROR =>
        .
        .
        .

```

Fig. 14 Sample Static Schedule

```

        when CRITICAL_OP1_TIMING_ERROR =>
            .
            .
            .
        end;
    end loop
end SCHEDULE;

begin
    null;
end STATIC_SCHEDULE;

```

Fig. 14 Continued

If the operator appears in the list, a check is then made to determine if the operator has exceeded its authorized number of executions. If it has, an error message is printed and execution of the prototype terminates abnormally. If it hasn't exceeded its authorized number of executions, the Executed\_count field in the record is then incremented by one, adjustments are made to the operator's MET, a record of the adjustments is printed to a file called Information and execution of the prototype is resumed.

Assume for the moment that this is the first time this operator has exceeded its MET. Consequently, it will not be found in the Operators\_Overrun list. At this point the user is queried as to which of two possible courses of action he would like to take. This is illustrated in Fig. 15. If the user opts for A, prototype execution terminates. If the user opts for B, a record for the operator is then inserted



in the Operators\_Overrun list, an error message is printed to file Information, adjustments are made to the operator's MET and a record of this is printed to Information. Fig. 16

timing error from operator CRITICAL\_OP2

Execution of the prototype has been suspended because an operator exceeded its maximum execution time. The operator causing the error is:

CRITICAL\_OP2

Do you want to

- A. Terminate execution of the prototype?
- B. Adjust the execution time of the operator and continue execution of the prototype?

Type the letter preceding the option you want.

Fig. 15 Sample User Query

EXECUTION HAS BEEN SUSPENDED OR HAS TERMINATED ABNORMALLY

The following operator did not complete execution before its maximum execution time was expired. The operator which caused the error is:

CRITICAL\_OP2

The maximum execution time for operator CRITICAL\_OP2 was increased by 3.0200000E+00.

The new ending time for operator CRITICAL\_OP2 from the start of the period within the static schedule is 1.5020000E+01.

EXECUTION HAS BEEN SUSPENDED OR HAS TERMINATED ABNORMALLY

The following operator did not complete execution before its maximum execution time was expired. The operator which caused the error is:

CRITICAL\_OP3

The maximum execution time for operator CRITICAL\_OP3 was increased by 1.7400000E+00.

The new ending time for operator CRITICAL\_OP3 from the start of the period within the static schedule is 1.5740000E+01.

Fig. 16 Contents of File Information

is an illustration of the possible contents of file Information. Note, the printing of the adjustment times to file Information represents a modification to the earlier implementation.

#### **F. ADDITIONAL RUNTIME SUPPORT**

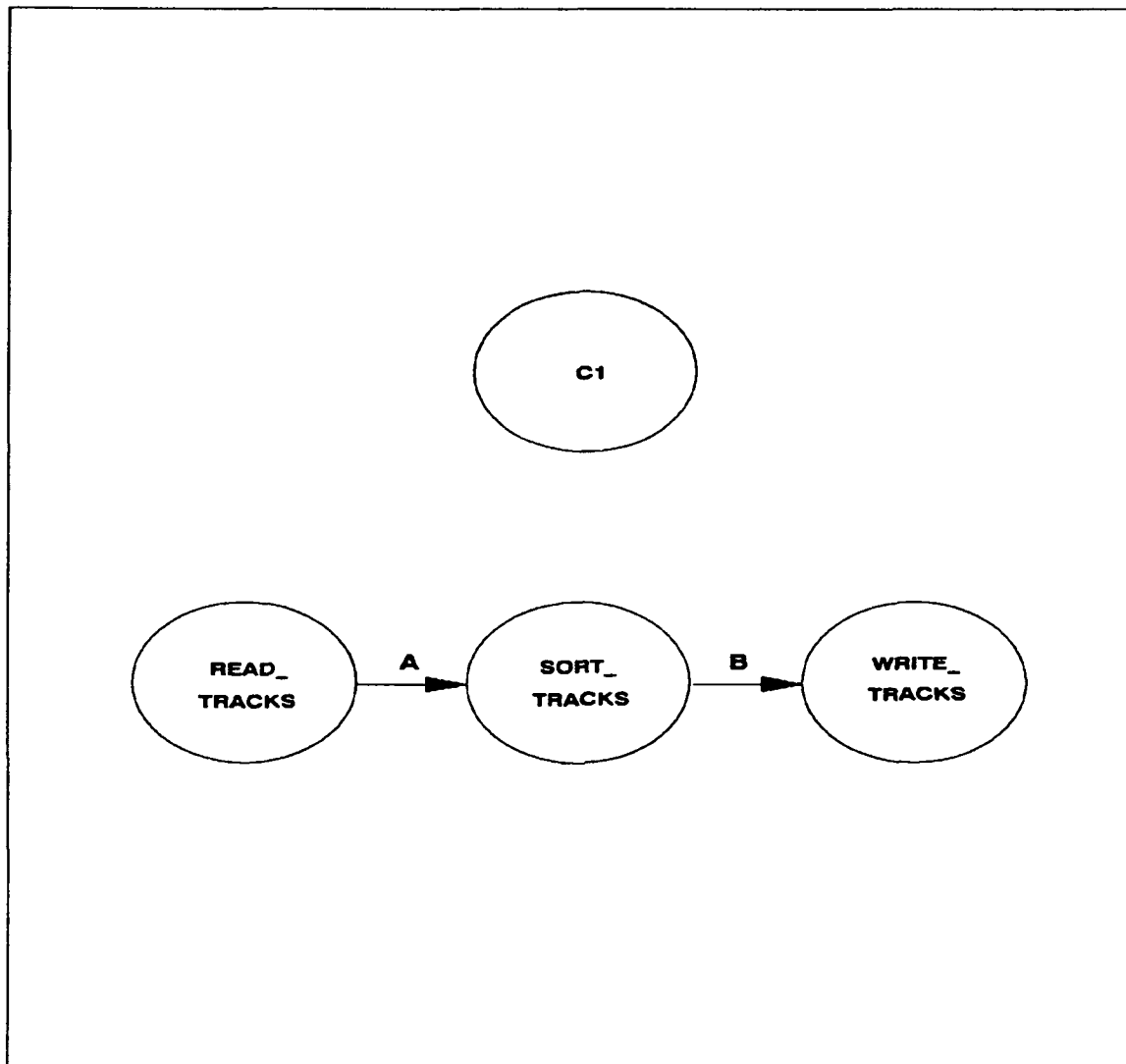
In the description of what constitutes a prototype at the beginning of this chapter, reference was made to a group of packages called simply, ADDITIONAL RUNTIME SUPPORT. With the exception of PRIORITY\_DEFINITIONS, which was discussed already, these packages provide various types and operations which are essential to the prototype's execution. In the interest of clarity and completeness, the code for these packages is provided as Appendix E.

## CHAPTER V. PROTOTYPE EXAMPLE

This chapter contains a prototype description and the corresponding prototype actually generated by the execution support system of CAPS. The example is based on the command and control system for a HAWK Air Defense Guided Missile System Battery. The mission of the HAWK system is to detect and destroy low to medium altitude, hostile, airborne targets. The HAWK missile system detects, identifies, tracks, engages, and destroys airborne targets. The system performs these functions against extremely low-altitude and medium-altitude targets while retaining a high degree of mobility for rapid deployment with the Army in the field.

Fig. 17 is a very small section of the overall dataflow diagram for the command and control system. This particular diagram is modeling the part of the system that provides to the Tactical Control Officer (TCO) a continuously updated tactical summary. Track data are read, sorted by category and then written to a tactical display located by the TCO. C1 is a composite operator. READ\_TRACKS, SORT\_TRACKS and WRITE\_TRACKS are atomic operators which represent the

realization of C1.



**Fig. 17 Dataflow Diagram**

Fig. 18 is the prototype description corresponding to the dataflow diagram in Fig. 17. As can be seen, operators READ\_TRACKS, SORT\_TRACKS and WRITE\_TRACKS are time-critical. More specifically though, they're periodic. Every 20

seconds they will execute. A and B are data streams. By virtue of the fact A does not appear in a "TRIGGERED BY ALL" constraint of SORT\_TRACKS, it is a sampled stream and will be implemented as such. Likewise for B. By virtue of the fact it does not appear in a "TRIGGERED BY ALL" constraint of WRITE\_TRACKS, it too is a sampled stream. STR\_LIST is a user defined type.

```

OPERATOR C1
SPECIFICATION
    MAXIMUM EXECUTION TIME 14 sec
END
IMPLEMENTATION GRAPH
    A.READ_TRACKS->SORT_TRACKS
    B.SORT_TRACKS->WRITE_TRACKS
    DATA STREAM A : STR_LIST,
                  B : STR_LIST
CONTROL CONSTRAINTS
    OPERATOR READ_TRACKS
        PERIOD 20 sec
    OPERATOR SORT_TRACKS
        PERIOD 20 sec
    OPERATOR WRITE_TRACKS
        PERIOD 20 sec
DESCRIPTION ( text )
END
OPERATOR READ_TRACKS

```

Fig. 18 Prototype Description

```

SPECIFICATION

  OUTPUT A : STR_LIST
  MAXIMUM EXECUTION TIME 10 sec

END

IMPLEMENTATION ADA READ_TRACKS
END

OPERATOR SORT_TRACKS

SPECIFICATION

  INPUT A : STR_LIST
  OUTPUT B : STR_LIST
  MAXIMUM EXECUTION TIME 2 sec

END

IMPLEMENTATION ADA SORT_TRACKS
END

OPERATOR WRITE_TRACKS

SPECIFICATION

  INPUT B : STR_LIST
  MAXIMUM EXECUTION TIME 2 sec

END

IMPLEMENTATION ADA WRITE_TRACKS
END

```

Fig. 18 Continued

Fig. 19 is package SB which contains the reusable components extracted from the software base. Procedure READ\_TRACKS basically just keeps reading track data from file INPUT\_FILE until it encounters the END\_OF\_FILE condition. SORT\_TRACKS makes use of the reusable component QUICKSORT to sort the tracks by category. And finally, WRITE\_TRACKS writes the data to the screen.

Fig. 20 is the output of the translator after it reads and processes the prototype description given in Fig. 18.

The statement

```
package DS_A is new SAMPLED_BUFFER(STR_LIST);
```

is the instantiation for data stream A. The statement

```
package DS_B is new SAMPLED_BUFFER(STR_LIST);
```

```
with TEXT_IO; use TEXT_IO;
with ORDERING;
with PSDL_EXCEPTIONS; use PSDL_EXCEPTIONS;
package SB is
  type STRING_REC is record
    NAME : STRING (1..80);
  end record;
  type STR_LIST is array (INTEGER range 1..10) of STRING_REC;
  procedure READ_TRACKS (DATA : in out STR_LIST);
  procedure SORT_TRACKS (L : in STR_LIST; M : in out STR_LIST);
  procedure WRITE_TRACKS (L : in STR_LIST);
end SB;

package body SB is
  function "<" (X : in STRING_REC;
               Y : in STRING_REC) return Boolean is
  begin
    return (X.NAME (1) < Y.NAME (1));
  end "<";
  package INT_INC is new
    ORDERING.QUICKSORT (STRING_REC, INTEGER, "<");
  use INT_INC;

  procedure READ_TRACKS (DATA : in out STR_LIST) is
    INPUT_FILE : FILE_TYPE;
    I, LAST : INTEGER;
    TEMP_STRING : STRING (1..80);
  begin
    OPEN (INPUT_FILE, IN_FILE, "INPUT_FILE");
    for J in 1..10 loop
      for K in 1..80 loop
        DATA (J).NAME (K) := ' ';
      end loop;
    end loop;
    I := 1;
    while (not (END_OF_FILE (INPUT_FILE))) loop
      GET_LINE (INPUT_FILE, TEMP_STRING, LAST);
      DATA (I).NAME (1..LAST) := TEMP_STRING (1..LAST);
```

Fig. 19 Reusable Components

```

    I := I + 1;
end loop;
CLOSE (INPUT_FILE);
end READ_TRACKS;

procedure SORT_TRACKS (L : in STR_LIST; M : in out STR_LIST) is
begin
    M := L;
    QUICKSORT (INT_INC.List (M)); -- Sort in increasing sequence
end SORT_TRACKS;

procedure WRITE_TRACKS (L : in STR_LIST) is
begin
    NEW_LINE;
    for I in 1..10 loop
        PUT_LINE (L (I).NAME (1..80));
        NEW_LINE;
    end loop;
end WRITE_TRACKS;
end SB;

```

Fig. 19 Continued

```

package TL is
    procedure READ_TRACKS_DRIVER;
    procedure SORT_TRACKS_DRIVER;
    procedure WRITE_TRACKS_DRIVER;
end TL;

with SB; use SB;
with PSDL_SYSTEM; use PSDL_SYSTEM;
package body TL is

    package C1_SPEC is

        package DS_A is new SAMPLED_BUFFER(STR_LIST);
        package DS_B is new SAMPLED_BUFFER(STR_LIST);

    end C1_SPEC;

    procedure READ_TRACKS_DRIVER is
        A: STR_LIST;
    begin
        READ_TRACKS(A);
        C1_SPEC.DS_A.BUFFER.WRITE(A);
    end READ_TRACKS_DRIVER;

    procedure SORT_TRACKS_DRIVER is
        A: STR_LIST;
    B: STR_LIST;
    begin
        C1_SPEC.DS_A.BUFFER.READ(A);
        SORT_TRACKS(A, B);
    end SORT_TRACKS_DRIVER;
end TL;

```

Fig. 20 DRIVER Procedures



```

        C1_SPEC.DS_B.BUFFER.WRITE(B);
    end SORT_TRACKS_DRIVER;

    procedure WRITE_TRACKS_DRIVER is
        B: STR_LIST;
    begin
        C1_SPEC.DS_B.BUFFER.READ(B);
        WRITE_TRACKS(B);
    end WRITE_TRACKS_DRIVER;

end TL;

```

Fig. 20 Continued

is the instantiation for data stream B. The procedures READ\_TRACKS\_DRIVER, etc. are the drivers for the reusable components given in Fig. 19.

Fig. 21 is the output of the dynamic scheduler. It consists of a package DS\_PACKAGE containing a task DYNAMIC\_SCHEDULE. DYNAMIC\_SCHEDULE contains procedure calls to the non-time-critical operator DRIVERS in package TL. In the example in this chapter, there are no non-time-critical operators, consequently, DYNAMIC\_SCHEDULE contains no procedure calls. Another important item to take note of is the statement

```
pragma priority (DYNAMIC_SCHEDULE_PRIORITY);
```

This statement is needed to ensure that if the static schedule and the dynamic schedule are both vying for the processor, the static schedule will get it. The value of this priority must be less than the value of the priority in

the static schedule.

```
with TL; use TL;
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS;
package DS_PACKAGE is
  task DYNAMIC_SCHEDULE is
    pragma priority (DYNAMIC_SCHEDULE_PRIORITY);
  end DYNAMIC_SCHEDULE;
end DS_PACKAGE;

package body DS_PACKAGE is
  task body DYNAMIC_SCHEDULE is
  begin
    loop
      null;
    end loop;
  end DYNAMIC_SCHEDULE;
end DS_PACKAGE;
```

Fig. 21 Dynamic Schedule

Fig. 22 is the output of the static scheduler. It consists of procedure calls to the time-critical operator DRIVERS in package TL. Note that the value of the priority here has to be greater than the value of the priority in the dynamic schedule.

```
with GLOBAL_DECLARATIONS; use GLOBAL_DECLARATIONS;
with DS_DEBUG_PKG; use DS_DEBUG_PKG;
with TL; use TL;
with DS_PACKAGE; use DS_PACKAGE;
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS;
with CALENDAR; use CALENDAR;
with TEXT_IO; use TEXT_IO;
procedure STATIC_SCHEDULE is
  WRITE_TRACKS_TIMING_ERROR : exception;
  SORT_TRACKS_TIMING_ERROR : exception;
  READ_TRACKS_TIMING_ERROR : exception;
  task SCHEDULE is
    pragma priority (STATIC_SCHEDULE_PRIORITY);
  end SCHEDULE;

  task body SCHEDULE is
    PERIOD : duration := duration(20);
```

Fig. 22 Static Schedule

```

READ_TRACKS_STOP_TIME1 : duration := duration(10);
SORT_TRACKS_STOP_TIME2 : duration := duration(12);
WRITE_TRACKS_STOP_TIME3 : duration := duration(14);
SLACK_TIME : duration;
START_OF_PERIOD : time := clock;
CURRENT_TIME : duration;
begin
  loop
    begin
      READ_TRACKS_DRIVER;
      SLACK_TIME := START_OF_PERIOD + READ_TRACKS_STOP_TIME1 - CLOCK;
      if SLACK_TIME >= 0.0 then
        delay (SLACK_TIME);
      else
        raise READ_TRACKS_TIMING_ERROR;
      end if;
      delay (START_OF_PERIOD + READ_TRACKS_STOP_TIME1 - CLOCK);

      SORT_TRACKS_DRIVER;
      SLACK_TIME := START_OF_PERIOD + SORT_TRACKS_STOP_TIME2 - CLOCK;
      if SLACK_TIME >= 0.0 then
        delay (SLACK_TIME);
      else
        raise SORT_TRACKS_TIMING_ERROR;
      end if;
      delay (START_OF_PERIOD + SORT_TRACKS_STOP_TIME2 - CLOCK);

      WRITE_TRACKS_DRIVER;
      SLACK_TIME := START_OF_PERIOD + WRITE_TRACKS_STOP_TIME3 - CLOCK;
      if SLACK_TIME >= 0.0 then
        delay (SLACK_TIME);
      else
        raise WRITE_TRACKS_TIMING_ERROR;
      end if;
      START_OF_PERIOD := START_OF_PERIOD + PERIOD;
      delay (START_OF_PERIOD - clock);
    exception
      when WRITE_TRACKS_TIMING_ERROR =>
        PUT_LINE("timing error from operator WRITE_TRACKS");
        CURRENT_TIME := clock - START_OF_PERIOD;
        DS_DEBUG.RUNTIME_MET_FAILURE (
          VARSTRING.VSTR("WRITE_TRACKS"),
          CURRENT_TIME, WRITE_TRACKS_STOP_TIME3, PERIOD);
        START_OF_PERIOD := clock;
      when SORT_TRACKS_TIMING_ERROR =>
        PUT_LINE("timing error from operator SORT_TRACKS");
        CURRENT_TIME := clock - START_OF_PERIOD;
        DS_DEBUG.RUNTIME_MET_FAILURE (
          VARSTRING.VSTR("SORT_TRACKS"),
          CURRENT_TIME, SORT_TRACKS_STOP_TIME2, PERIOD);
        START_OF_PERIOD := clock;
      when READ_TRACKS_TIMING_ERROR =>
        PUT_LINE("timing error from operator READ_TRACKS");
        CURRENT_TIME := clock - START_OF_PERIOD;
        DS_DEBUG.RUNTIME_MET_FAILURE (

```

Fig. 22 Continued

```

        VARSTRING.VSTR("READ_TRACKS"),
        CURRENT_TIME, READ_TRACKS_STOP_TIME1, PERIOD);
    START_OF_PERIOD := clock;
    end;
    end loop;
end SCHEDULE;

begin
    null;
end STATIC_SCHEDULE;

```

Fig. 22 Continued

Once the translator, static scheduler and dynamic scheduler have completed, the user interface takes their outputs as well as the packages: PSDL\_SYSTEM, PSDL\_EXCEPTIONS, SB, Global\_Declarations, DS\_Debug\_PKG, TIMERS, VSTRINGS, List\_Single\_Unbounded\_Unmanaged and PRIORITY\_DEFINITIONS and compiles and links them, thus forming the executable prototype. This prototype is then run. Fig. 23 is a sample input for the prototype. Fig. 24

Identified	Azimuth	Range (km)	Heading	Speed (mph)
hostile	320	425	140	1500
unknown	40	250	240	750
friendly	80	75	360	1000
friendly	100	20	270	1000
friendly	250	130	90	500
hostile	330	450	150	1500
hostile	300	475	120	1500
unknown	45	750	180	1000
unknown	30	650	210	1000

Fig. 23 Sample Track Data

is the corresponding output.

Identified	Azimuth	Range (km)	Heading	Speed (mph)
friendly	100	20	270	1000
friendly	80	75	360	1000
friendly	250	130	90	500
hostile	300	475	120	1500
hostile	320	425	140	1500
hostile	330	450	150	1500
unknown	30	650	210	1000
unknown	45	750	180	1000
unknown	40	250	240	750

Fig. 24 Corresponding Output

## VI. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

Integration is sort of a nebulous term. Integration as used throughout this thesis has meant: 1. make modifications to the component to make it work if it doesn't already and 2. then make modifications to the component to make it function as part of the execution support system. In the case of the translator, we saw the need for both types of modifications. In the case of the static scheduler and of the debugger, just the latter type of modification was required. Finally, in the case of the dynamic scheduler we had a situation where modifications would have been so extensive, that a new implementation was deemed more efficient.

The purpose of this thesis was to provide a tool that enables the execution of prototypes written in PSDL. That has been accomplished. With the addition of the debugger the designer also has the capability of changing an operator's MET dynamically and of recording all operator time adjustments.

## B. RECOMMENDATIONS

There are significant opportunities for future research in the area of the execution support system. One possibility is the expansion of the debugger. As it is currently implemented, entries `Buffer_Underflow` and `Buffer_Overflow` provide only an identification type function. If a call is made to either of them, the only action taken is to print an error message to file `Information` and then terminate the prototype's execution. Perhaps the capability of correcting these error dynamically, as it is for `Runtime_MET_Failure`, can be built in to the debugger.

Another possibility for future research is in the way that the user interface interacts with the execution support system. The way that CAPS is implemented now, when the designer finishes construction of the prototype description and wishes to invoke the execution support system, he or she does so by selecting an `Execute` option off of a menu. What happens then is the user interface submits the prototype description to the translator for creation of package `TL`. Once the translator finishes, the user interface next submits the prototype description to the static scheduler

for processing. After the static scheduler finishes, the user interface then invokes the dynamic scheduler. After the dynamic scheduler finishes the user interface next compiles and links the necessary files, creating the executable prototype which is immediately run. At no point in this process though does the user interface query the designer as to whether or not they would like to continue, even if something should go awry along the way like the static scheduler not being able to derive a schedule. The user interface needs to be changed so that the Execute option is broken down into perhaps three options like: Translate, Compile and Run.



## APPENDIX A. DATA STREAM IMPLEMENTATION

```
with PRIORITY_DEFINITIONS; use PRIORITY_DEFINITIONS;
with vstrings, TIMERS;
package PSDL_SYSTEM is
```

```
    package PSDL_STRINGS is new vstrings(50);
    type      PSDL_TIMER is new TIMERS.TIMER;
```

```
    BUFFER_UNDERFLOW, BUFFER_OVERFLOW: exception;
```

```
    generic
```

```
        type ELEMENT_TYPE is private;
    package SAMPLED_BUFFER is
        task BUFFER is
            pragma PRIORITY(BUFFER_PRIORITY);
            entry CHECK(NEW_DATA: out BOOLEAN);
            entry WRITE(VALUE: in ELEMENT_TYPE);
            entry READ(VALUE: out ELEMENT_TYPE);
        end BUFFER;
        function NEW_DATA return BOOLEAN;
    end SAMPLED_BUFFER;
```

```
    generic
```

```
        type ELEMENT_TYPE is private;
    package FIFO_BUFFER is
        task BUFFER is
            pragma PRIORITY(BUFFER_PRIORITY);
            entry CHECK(NEW_DATA: out BOOLEAN);
            entry WRITE(VALUE: in ELEMENT_TYPE);
            entry READ(VALUE: out ELEMENT_TYPE);
        end BUFFER;
        function NEW_DATA return BOOLEAN;
    end FIFO_BUFFER;
```

```
    generic
```

```
        type ELEMENT_TYPE is private;
        INITIAL_VALUE: ELEMENT_TYPE;
    package STATE_VARIABLE is
        task BUFFER is
            pragma PRIORITY(BUFFER_PRIORITY);
            entry CHECK(NEW_DATA: out BOOLEAN);
            entry READ(VALUE: out ELEMENT_TYPE);
            entry WRITE(VALUE: in ELEMENT_TYPE);
        end BUFFER;
        function NEW_DATA return BOOLEAN;
```

```

end STATE_VARIABLE;
end PSDL_SYSTEM;

```

```

package body PSDL_SYSTEM is

```

```

    package body SAMPLED_BUFFER is

```

```

        task body BUFFER is

```

```

            BUFFER: ELEMENT_TYPE;

```

```

            FRESH: BOOLEAN := false;

```

```

        begin

```

```

            loop

```

```

                select

```

```

                    accept CHECK(NEW_DATA: out BOOLEAN) do

```

```

                        NEW_DATA := FRESH;

```

```

                    end CHECK;

```

```

                or

```

```

                    accept READ(VALUE: out ELEMENT_TYPE) do

```

```

                        VALUE := BUFFER; FRESH := false;

```

```

                    end READ;

```

```

                or

```

```

                    accept WRITE(VALUE: in ELEMENT_TYPE) do

```

```

                        BUFFER := VALUE; FRESH := true;

```

```

                    end WRITE;

```

```

                end select;

```

```

            end loop;

```

```

        end BUFFER;

```

```

        function NEW_DATA return BOOLEAN is

```

```

            RESULT: BOOLEAN;

```

```

        begin

```

```

            BUFFER.CHECK(RESULT);

```

```

            return(RESULT);

```

```

        end NEW_DATA;

```

```

    end SAMPLED_BUFFER;

```

```

    package body FIFO_BUFFER is

```

```

        task body BUFFER is

```

```

            BUFFER: ELEMENT_TYPE;

```

```

            FRESH: BOOLEAN := false;

```

```

        begin

```

```

            loop

```

```

                select

```

```

                    accept CHECK(NEW_DATA: out BOOLEAN) do

```

```

                        NEW_DATA := FRESH;

```

```

                    end CHECK;

```

```

                or

```

```

                    accept READ(VALUE: out ELEMENT_TYPE) do

```

```

                        if FRESH then

```

```

                            VALUE := BUFFER; FRESH := false;

```

```

                        else raise BUFFER_UNDERFLOW; end if;

```

```

        end READ;
    or
        accept WRITE(VALUE: in ELEMENT_TYPE) do
            if not FRESH then
                BUFFER := VALUE; FRESH := true;
            else raise BUFFER_OVERFLOW; end if;
        end WRITE;
    end select;
end loop;
end BUFFER;

function NEW_DATA return BOOLEAN is
    RESULT: BOOLEAN;
begin
    BUFFER.CHECK(RESULT);
    return(RESULT);
end NEW_DATA;
end FIFO_BUFFER;

package body STATE_VARIABLE is
    task body BUFFER is
        BUFFER: ELEMENT_TYPE := INITIAL_VALUE;
        FRESH: BOOLEAN := true;
    begin
        loop
            select
                accept CHECK(NEW_DATA: out BOOLEAN) do
                    NEW_DATA := FRESH;
                end CHECK;
            or
                accept READ(VALUE: out ELEMENT_TYPE) do
                    VALUE := BUFFER; FRESH := false;
                end READ;
            or
                accept WRITE(VALUE: in ELEMENT_TYPE) do
                    BUFFER := VALUE; FRESH := true;
                end WRITE;
            end select;
        end loop;
    end BUFFER;

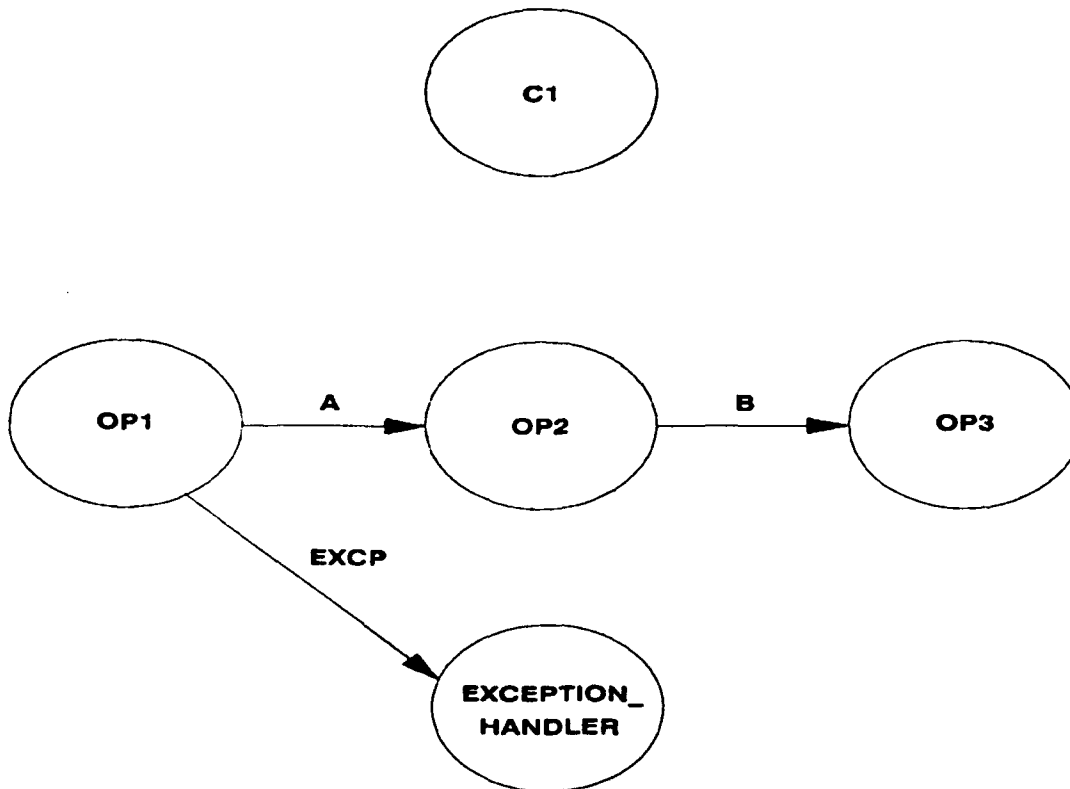
    function NEW_DATA return BOOLEAN is
        RESULT: BOOLEAN;
    begin
        BUFFER.CHECK(RESULT);
        return RESULT;
    end NEW_DATA;
end STATE_VARIABLE;
end PSDL_SYSTEM;

```

## APPENDIX B. EXCEPTION HANDLING EXAMPLE

This appendix contains a sample prototype which performs no particular function. The purpose of this example is to illustrate the approach to exception handling adopted in this thesis.

### A. DATA FLOW DIAGRAM



## B. PROTOTYPE DESCRIPTION

OPERATOR C1

### SPECIFICATION

MAXIMUM EXECUTION TIME 14 sec

END

### IMPLEMENTATION GRAPH

A.OP1->OP2

EXCP.OP1->EXCEPTION\_HANDLER

B.OP2->OP3

DATA STREAM A : INTEGER,  
EXCP : PSDL\_EXCEPTION,  
B : INTEGER

### CONTROL CONSTRAINTS

OPERATOR OP1

PERIOD 20 sec

EXCEPTION OUT\_OF\_RANGE IF A > 100

OPERATOR OP2

PERIOD 20 sec

OPERATOR OP3

PERIOD 20 sec

OPERATOR EXCEPTION\_HANDLER

TRIGGERED BY ALL EXCP IF EXCP = OUT\_OF\_RANGE

PERIOD 20 sec

END

OPERATOR OP1

### SPECIFICATION

OUTPUT A : INTEGER

OUTPUT EXCP : PSDL\_EXCEPTION

MAXIMUM EXECUTION TIME 10 sec

EXCEPTIONS NEGATIVE\_NUMBER

END

IMPLEMENTATION ADA OP1

END

OPERATOR OP2

SPECIFICATION

INPUT A : INTEGER  
OUTPUT B : INTEGER  
MAXIMUM EXECUTION TIME 2 sec

END

IMPLEMENTATION ADA OP2

END

OPERATOR OP3

SPECIFICATION

INPUT B : INTEGER  
MAXIMUM EXECUTION TIME 2 sec

END

IMPLEMENTATION ADA OP3

END

OPERATOR EXCEPTION\_HANDLER

SPECIFICATION

INPUT EXCP : PSDL\_EXCEPTION  
MAXIMUM EXECUTION TIME 2 sec

END

IMPLEMENTATION ADA EXCEPTION\_HANDLER

END

### C. PARTIAL ADA IMPLEMENTATION OF PROTOTYPE DESCRIPTION

```
package TL is
  procedure OP1_DRIVER;
  procedure OP2_DRIVER;
  procedure OP3_DRIVER;
  procedure EXCEPTION_HANDLER_DRIVER;
end TL;
```

```
with PSDL_SYSTEM; use PSDL_SYSTEM;
```

```

with PSDL_EXCEPTIONS; use PSDL_EXCEPTIONS;
with SB; use SB;
package body TL is

    package C1_SPEC is

        package DS_A is new SAMPLED_BUFFER(INTEGER);
        package DS_B is new SAMPLED_BUFFER(INTEGER);
        package DS_EXCP is new FIFO_BUFFER(PSDL_EXCEPTION);

    end C1_SPEC;

    procedure OP1_DRIVER is
        A : INTEGER;

    begin
        OP1(A);
        if A > 100 then
            C1_SPEC.DS_EXCP.BUFFER.WRITE(INDEX(CHARACTER_STRING.
                VSTR("OUT_OF_RANGE")));
        else
            C1_SPEC.DS_A.BUFFER.WRITE(A);
        end if;

        exception
            when NEGATIVE_NUMBER =>
                C1_SPEC.DS_EXCP.BUFFER.WRITE(INDEX(CHARACTER_
                    STRING.VSTR("NEGATIVE_NUMBER")));
    end OP1_DRIVER;

    procedure OP2_DRIVER is
        A : INTEGER;
        B : INTEGER;

    begin
        C1_SPEC.DS_A.BUFFER.READ(A);
        OP2(A, B);
        C1_SPEC.DS_B.BUFFER.WRITE(B);
    end OP2_DRIVER;

    procedure OP3_DRIVER is
        B : INTEGER;

    begin
        C1_SPEC.DS_B.BUFFER.READ(B);
        OP3(B);
    end OP3_DRIVER;

    procedure EXCEPTION_HANDLER_DRIVER is
        EXCP : PSDL_EXCEPTION;

```

```

begin
  if C1_SPEC.DS_EXCP.NEW_DATA then
    C1_SPEC.DS_EXCP.BUFFER.READ(EXCP);
    if EXCP = (INDEX(CHARACTER_STRING.VSTR("OUT_OF_
      RANGE"))) then
      EXCEPTION_HANDLER(EXCP);
    end if;
  end if;
end EXCEPTION_HANDLER_DRIVER;

begin
  DECLARE_EXCEPTION(CHARACTER_STRING.VSTR("OUT_OF_RANGE"));
  DECLARE_EXCEPTION(CHARACTER_STRING.VSTR("NEGATIVE_NUMBER")
);
end TL;

with TEXT_IO; use TEXT_IO;
with PSDL_EXCEPTIONS; use PSDL_EXCEPTIONS;
package SB is
  NEGATIVE_NUMBER : exception;
  procedure OP1 (DATA : in out INTEGER);
  procedure OP2 (L : in INTEGER; M : in out INTEGER);
  procedure OP3 (L : in INTEGER);
  procedure EXCEPTION_HANDLER (L : in PSDL_EXCEPTION);
end SB;

package body SB is

  procedure OP1 (DATA : in out INTEGER) is
  begin
    .
    .
    .
    if (DATA < 0) then
      raise NEGATIVE_NUMBER;
    end if;
    .
    .
    .

  end OP1;

  procedure OP2 (L : in INTEGER; M : in out INTEGER) is
  begin
    .
    .
    .

  end OP2;

  procedure OP3 (L : in INTEGER) is
  begin

```



```

      .
      .
      .
end OP3;

procedure EXCEPTION_HANDLER (L : in PSDL_EXCEPTION) is
begin
  new_line;
  if (CHARACTER_STRING.STR (NAME (L))) = "OUT_OF_RANGE"
  then
    put_line("Out of Range");
  elsif (CHARACTER_STRING.STR (NAME (L))) = "NEGATIVE_
NUMBER" then
    put_line("Negative Number");
  end if;
  new_line;
end EXCEPTION_HANDLER;

end SB;

```

#### D. SUPPORTING ADA PACKAGE

```

with VSTRINGS;
with List_Single_Unbounded_Unmanaged;
package PSDL_EXCEPTIONS is
-- Definition of Abstract Data Type

  type PSDL_EXCEPTION is private;
  package CHARACTER_STRING is new VSTRINGS (80);
  procedure DECLARE_EXCEPTION (E : in CHARACTER_STRING.
VSTRING);
  function NAME (E : in PSDL_EXCEPTION) return CHARACTER_
STRING.VSTRING;
  function INDEX (E : in CHARACTER_STRING.VSTRING) return
PSDL_EXCEPTION;
private
  type PSDL_EXCEPTION is range 1..1000;
end PSDL_EXCEPTIONS;

package body PSDL_EXCEPTIONS is

  package EXCEPTION_LIST is new
    List_Single_Unbounded_Unmanaged (Item => CHARACTER_
STRING.VSTRING);

  DECLARED_EXCEPTIONS : EXCEPTION_LIST.List;

  function IS_EQUAL (LEFT : in CHARACTER_STRING.VSTRING;
                     RIGHT : in CHARACTER_STRING.VSTRING)
return BOOLEAN is

```

```

begin
    return (CHARACTER_STRING."=" (LEFT, RIGHT));
end IS_EQUAL;

procedure DECLARE_EXCEPTION (E : in CHARACTER_STRING
.VSTRING) is
begin
    EXCEPTION_LIST.Construct (E, DECLARED_EXCEPTIONS);
end DECLARE_EXCEPTION;

function NAME (E : in PSDL_EXCEPTION) return CHARACTER_
STRING.VSTRING is
    TEMPORARY_LIST : EXCEPTION_LIST.List := DECLARED_
    EXCEPTIONS;
begin
    for INDEX in 1..(E-1) loop
        TEMPORARY_LIST := EXCEPTION_LIST.Tail_Of (TEMPORARY_
        LIST);
    end loop;
    return (EXCEPTION_LIST.Head_Of (TEMPORARY_LIST));
end NAME;

function INDEX (E : in CHARACTER_STRING.VSTRING) return
PSDL_EXCEPTION is
    TEMPORARY_LIST : EXCEPTION_LIST.List := DECLARED_
    EXCEPTIONS;
    I : PSDL_EXCEPTION := 1;
begin
    while not EXCEPTION_LIST.Is_Null (TEMPORARY_LIST) loop
        if IS_EQUAL (E, EXCEPTION_LIST.Head_Of (TEMPORARY_
        LIST)) then
            return I;
        else
            TEMPORARY_LIST := EXCEPTION_LIST.Tail_Of (TEMPORARY_
            LIST);
            I := I + 1;
        end if;
    end loop;
end INDEX;

end PSDL_EXCEPTIONS;

```

## APPENDIX C. DYNAMIC SCHEDULER IMPLEMENTATION

```

with TEXT_IO; use TEXT_IO;
procedure DYNAMIC_SCHEDULER is
  NON_CRITS      : FILE_TYPE;
  DSV3           : FILE_TYPE;
  IN_STRING      : STRING(1..72);
  LAST           : NATURAL;
begin
  OPEN(NON_CRITS, IN_FILE,
"/n/suns2/work/caps/prototypes/non_crits");
  CREATE(DSV3, OUT_FILE,
"/n/suns2/work/caps/prototypes/ds.a");
  PUT_LINE(DSV3, "with TL; use TL;");
  PUT_LINE(DSV3, "with PRIORITY_DEFINITIONS; use
PRIORITY_DEFINITIONS;");
  PUT_LINE(DSV3, "package DS_PACKAGE is");
  PUT_LINE(DSV3, "  task DYNAMIC_SCHEDULE is");
  -- system defined priority for dynamic schedule
  PUT_LINE(DSV3, "    pragma priority
(DYNAMIC_SCHEDULE_PRIORITY);");
  PUT_LINE(DSV3, "  end DYNAMIC_SCHEDULE;");
  PUT_LINE(DSV3, "end DS_PACKAGE;");
  NEW_LINE(DSV3);
  PUT_LINE(DSV3, "package body DS_PACKAGE is");
  PUT_LINE(DSV3, "  task body DYNAMIC_SCHEDULE is");
  PUT_LINE(DSV3, "    begin");
  PUT_LINE(DSV3, "      delay (1.0);");
  PUT_LINE(DSV3, "      loop");
  while not END_OF_FILE(NON_CRITS) loop
    begin
      GET_LINE(NON_CRITS, IN_STRING, LAST);
      PUT(DSV3, "    ");
      for INDEX in 1..LAST loop
        PUT(DSV3, IN_STRING(INDEX));
      end loop;
      PUT_LINE(DSV3, ";");
    end;
  end loop;
  PUT_LINE(DSV3, "    null;");
  PUT_LINE(DSV3, "  end loop;");
  PUT_LINE(DSV3, "  end DYNAMIC_SCHEDULE;");
  PUT_LINE(DSV3, "end DS_PACKAGE;");
end DYNAMIC_SCHEDULER;

```

## APPENDIX D. DEBUGGER

```
-----
--      This package contains information that must be declared globally --
-- for the Dynamic_Scheduler procedure. --
--      The library unit VSTRINGS is a generic string package. It --
-- contains the data type VSTRING and procedures to manipulate these --
-- strings. Since VSTRINGS is generic, it must be instantiated. The name --
-- of the instantiation must then be made visible. --
--      The instantiation is declared in a package so that type --
-- compatibility will be ensured among variables that the --
-- Dynamic_Scheduler will share among tasks. --
-----
with VSTRINGS;

package Global_Declarations is

    package VARSTRING is new VSTRINGS (160);
    use VARSTRING;
end Global_Declarations;

with Global_Declarations;
use Global_Declarations;

with TEXT_IO, CALENDAR;
use TEXT_IO, CALENDAR;

package DS_Debug_PKG is
--*   The specification for task DS_Debug contains three entry statements.*--
--*These statements identify errors that may be encountered when the opera*--
--*tors execute.*--

    task DS_Debug is
        pragma priority (10);
        entry Runtime_MET_Failure (Exception_Operator : VARSTRING.VSTRING;
                                   Current_Time : in duration;
                                   Operator_Ending_Time : in out duration;
                                   Period : in out duration);
        --*   The in value for Current_Time is the time the operator completed*--
        --*execution. The out value for Current_Time is the adjusted time*--
        --*backgrounds. Next_Start has as its value the time the next oper*--
        --*ator must start execution.*--

        entry Buffer_Underflow; --input queue empty
        entry Buffer_Overflow; --output queue full
```

```

end DS_Debug;
end DS_Debug_PKG;

```

```

package body DS_Debug_PKG is

```

```

    task body DS_Debug is

```

```

        type NODE;

```

```

        type LINK is access NODE;

```

```

    type NODE is

```

```

        record

```

```

            Operator : VARSTRING.VSTRING; --name of operator exceeding MET

```

```

            Executed_count : NATURAL;      --number of times operator has executed

```

```

            Next : LINK;

```

```

        end record;

```

```

    package FLOATIO is new TEXT_IO.FLOAT_IO (FLOAT);

```

```

    Exception_Operator : VARSTRING.VSTRING; --operator causing error

```

```

    Information : FILE_TYPE; --file containing error information

```

```

    Error_Exists : BOOLEAN := FALSE;

```

```

    Found : BOOLEAN := FALSE; --indicates if operator already in list

```

```

    Choice : CHARACTER := 'A'; --operator's decision as to continue/terminate

```

```

    Operators_Ovrrun : LINK := null; --list of operators that have exceeded
                                     -- their MET

```

```

    Current : LINK; --pointer to operator in list

```

```

    Difference : DURATION; --time over MET

```

```

    Max_Executions : CONSTANT NATURAL := 5; --maximum number of times an

```

```

                                     --operator whose MET is exceeded

```

```

                                     --can operate

```

```

--* The Find procedure identifies whether the operator is in the list.*--

```

```

--*Name contains the name of the operator with the runtime error. If the*--

```

```

--*operator is in the list, Current will point to it. If the operator is*--

```

```

--*not in the list, Current will point to the last node in the list. The*--

```

```

--*value of Found will identify if the operator is already in the list.*--

```

```

    procedure Find (Head : in LINK; Name : in VARSTRING.VSTRING;

```

```

                   Current : in out LINK; Found : out BOOLEAN) is

```

```

    begin

```

```

        Current := Head;

```

```

        if Current = null then --if no nodes in list

```

```

            Found := FALSE;

```

```

        elsif Current.Next = null then --if only one node in list

```

```

            if VARSTRING.equal (Current.Operator, Name) then

```

```

                Found := TRUE;

```

```

            else

```

```

                Found := FALSE;

```

```

            end if;

```

```

        else --traverse list

```

```

            while Current.Next /= null

```

```

        loop
            if VARSTRING.equal (Current.Operator, Name) then
                Found := TRUE;
            end if;
            Current := Current.Next;
        end loop;

        -- when traversing list, the last node will not be examined.
        -- following "if" ensures last node examined
        if Current.Next = null then
            if VARSTRING.equal (Current.Operator, Name) then
                Found := TRUE;
            else
                Found := FALSE;
            end if;
        end if;
    end if;
end Find;

```

--\* The Insert procedure will place a node at the end of the list. The\*--  
 --\*node will contain the name of the operator with the error and the number\*--  
 --\*of times the operator has executed. The number is initialized to one.\*--

```

procedure Insert (Head : in out LINK; Name : VARSTRING.VSTRING) is
    Temp_Pt : LINK;
    New_Node : LINK;

```

```

begin
    New_Node := new NODE' (Name, 1, null);

    if Head = null then
        Head := New_Node;
    else
        Temp_Pt := Head;
        while Temp_Pt.Next /= null
            loop
                Temp_Pt := Temp_Pt.Next;
            end loop;
        Temp_Pt.Next := New_Node;
    end if;
end Insert;

```

--\* The next five procedures print an error message to the file Informa\*--  
 --\*tion. The name of each procedure indicates the name of the error it is\*--  
 --\*processing. The last procedure is called when an operator has executed\*--  
 --\*more frequently than the permitted number of executions (for an operator\*--  
 --\*exceeding its MET).\*--

```

procedure Print_Buffer_Underflow_Message (Information : FILE_TYPE) is
begin
    PUT (Information, "EXECUTION TERMINATED ABNORMALLY.");

```

```

        NEW_LINE (Information);
        PUT (Information, "There was an attempt to read a data buffer ");
        PUT (Information, "that");
        NEW_LINE (Information);
        PUT (Information, "contained no data.");
        NEW_LINE (Information);
    end Print_Buffer_Underflow_Message;

procedure Print_Buffer_Overflow_Message (Information : FILE_TYPE) is
begin
    PUT (Information, "EXECUTION TERMINATED ABNORMALLY.");
    NEW_LINE (Information);
    PUT (Information, "There was an attempt to store data into a ");
    PUT (Information, "data buffer");
    NEW_LINE (Information);
    PUT (Information, "that was already full.");
    NEW_LINE (Information);
end Print_Buffer_Overflow_Message;

procedure Print_Runtime_MET_Failure_Message (Information : FILE_TYPE;
        Exception_Operator : VARSTRING.VSTRING) is
begin
    PUT (Information, "EXECUTION HAS BEEN SUSPENDED OR HAS ");
    PUT_LINE (Information, "TERMINATED ABNORMALLY");
    NEW_LINE (Information);
    PUT (Information, "The following operator did not complete ");
    PUT (Information, "execution ");
    NEW_LINE (Information);
    PUT (Information, "before its maximum execution time was ");
    PUT_LINE (Information, "expired. The operator");
    PUT (Information, "which caused the error is:");
    NEW_LINE (Information);
    PUT (Information, " ");
    VARSTRING.PUT (Information, Exception_Operator);
    NEW_LINE (Information);
    NEW_LINE (Information);
end Print_Runtime_MET_Failure_Message;

procedure Print_Adjustments_Made_Message (Information : FILE_TYPE;
        Exception_Operator : VARSTRING.VSTRING; Difference : in duration;
        Operator_Ending_Time : in duration; Period : in duration) is
begin
    PUT (Information, "The maximum execution time for operator ");
    VARSTRING.PUT_LINE (Information, Exception_Operator);
    PUT (Information, "was increased by ");
    FLOATIO.PUT (Information, FLOAT(Difference), 3, 7);
    PUT_LINE (Information, ".");
    PUT (Information, "The new ending time for operator ");
    VARSTRING.PUT_LINE (Information, Exception_Operator);
    PUT (Information, "from the start of the period within the ");
    PUT_LINE (Information, "static schedule ");

```

```

    PUT (Information, "is ");
    FLOATIO.PUT (Information, FLOAT(Operator_Ending_Time), 3, 7);
    PUT_LINE (Information, ".");
    NEW_LINE (Information);
end Print_Adjustments_Made_Message;

```

```

procedure Print_Too_Many_Executions_Message (Information : FILE_TYPE;
                                             Exception_Operator : VARSTRING.VSTRING) is
begin
    PUT (Information, "EXECUTION TERMINATED ABNORMALLY.");
    PUT (Information, "The following operator, which executes ");
    PUT_LINE (Information, "frequently, has a maximum");
    PUT (Information, "execution time that is not long enough. ");
    PUT_LINE (Information, "Execution has been");
    PUT (Information, "terminated because processing time is being ");
    PUT_LINE (Information, "wasted by having");
    PUT (Information, "to handle the error each time the operator ");
    PUT_LINE (Information, "executes. The operator is:");
    PUT (Information, " ");
    VARSTRING.PUT_LINE (Information, Exception_Operator);
end Print_Too_Many_Executions_Message;

```

--\* The following procedure is called when an operator first exceeds its\*--  
 --\*MET. The procedure queries the user as to whether to terminate or not.\*--  
 --\*The user is given three attempts to input valid data - either A or B.\*--  
 --\*If he has not provided valid data, the procedure will return a value\*--  
 --\*of A to terminate execution. Also, the procedure will print a message\*--  
 --\*stating that execution has been terminated due to invalid input.\*--

```

procedure Obtain_User_Choice (Exception_Operator : VARSTRING.VSTRING;
                              Choice : in out CHARACTER) is

```

```

    Count : INTEGER;

```

```

procedure Print_Too_Many_Tries_Message is

```

```

begin
    NEW_LINE;
    PUT ("You exceeded the number of attempts authorized to ");
    PUT ("enter data.");
    NEW_LINE;
    PUT ("Therefore, execution of the prototype has been ");
    PUT ("terminated.");
    NEW_LINE;
end Print_Too_Many_Tries_Message;

```

```

begin
    Count := 1;
    NEW_LINE;
    NEW_LINE;
    PUT ("Execution of the prototype has been suspended because an");
    NEW_LINE;
    PUT ("operator exceeded its maximum execution time. The");

```



```

NEW_LINE;
PUT_LINE ("operator causing the error is: ");
PUT ("    ");
VARSTRING.PUT (Exception_Operator);
NEW_LINE;
NEW_LINE;
PUT_LINE ("Do you want to ");
PUT_LINE ("A. Terminate execution of the prototype?");
PUT ("B. Adjust the execution time of the operator and continue");
NEW_LINE;
PUT ("    execution of the prototype?");
NEW_LINE;
NEW_LINE;
PUT_LINE ("Type the letter preceding the option you want.");

loop
    GET (Choice);
    NEW_LINE;
    NEW_LINE;

    if Choice = 'a' then
        Choice := 'A';
    end if;

    if Choice = 'b' then
        Choice := 'B';
    end if;

    exit when Choice = 'A' or Choice = 'B' or Count = 3;

    PUT ("You typed: ");
    PUT (Choice);
    NEW_LINE;
    PUT_LINE ("You must type either A or B.");

    Count := Count + 1;
end loop;

if Choice /= 'A' and Choice /= 'B' then
    Choice := 'A';
    Print_Too_Many_Tries_Message;
end if;
end Obtain_User_Choice;

begin
    -- main body of task DS_Debug
    create (FILE => Information,
        MODE => OUT_FILE,
        NAME => "Information");

```

```

loop
  select
    accept Buffer_Underflow do
      Error_Exists := true;
      Print_Buffer_Underflow_Message (Information);
    end Buffer_Underflow;
  or
    accept Buffer_Overflow do
      Error_Exists := true;
      Print_Buffer_Overflow_Message (Information);
    end Buffer_Overflow;
  or
    accept Runtime_MET_Failure
      (Exception_Operator : VARSTRING.VSTRING;
       Current_Time : in duration;
       Operator_Ending_Time : in out duration;
       Period : in out duration) do

      Find (Operators_Overrun, Exception_Operator, Current, Found);
      --is operator in Operators_Overrun list?

      if Found then
        --check number of executions
        --if operator executed less than that authorized, update
        if Current.Executed_count <= Max_Executions then
          Current.Executed_count := Current.Executed_count + 1;
        else
          --terminate and print error message
          Error_Exists := true;
          PUT_LINE ("EXECUTION TERMINATED ABNORMALLY.");
          Print_Too_Many_Executions_Message (Information,
            Exception_Operator);
        end if;
      else
        --query user as to terminate/continue
        Obtain_User_Choice (Exception_Operator, Choice);

        case Choice is
          when 'A' => Error_Exists := true; --terminate
          when 'B' => Insert (Operators_Overrun,
            Exception_Operator);
            --insert operator into Operators_Overrun list
          when others => null;
        end case;

        Print_Runtime_MET_Failure_Message (Information,
          Exception_Operator);
        --print error message first time operator exceeds MET
      end if;

      Difference := Current_Time - Operator_Ending_Time;
      --calculate time over MET
      Operator_Ending_Time := Operator_Ending_Time + Difference;
      --reset time to the new operator ending time

```

```

        Period := Period + Difference;
        Print_Adjustments_Made_Message (Information,
                                         Exception_Operator, Difference,
                                         Operator_Ending_Time, Period);
    end Runtime_MET_Failure;
end select;

if Error_Exists then
    close (Information);
    exit;
end if;

end loop;
end DS_Debug;
end Ds_Debug_PKG;

```

## APPENDIX E. ADDITIONAL RUNTIME SUPPORT

### A. TIMERS

with CALENDAR;  
package TIMERS is

    subtype MICROSEC is NATURAL;  
    type TIMER is private;

    procedure RESET (NAME : in out TIMER);  
    procedure START (NAME : in out TIMER);  
    procedure STOP (NAME : in out TIMER);  
    function READ (NAME : in TIMER) return MICROSEC;  
    function LT (PT : TIMER; T : MICROSEC) return BOOLEAN;  
    function LT (T : MICROSEC; PT : TIMER) return BOOLEAN;  
    function GT (PT : TIMER; T : MICROSEC) return BOOLEAN;  
    function GT (T : MICROSEC; PT : TIMER) return BOOLEAN;  
    function LTE (PT : TIMER; T : MICROSEC) return BOOLEAN;  
    function LTE (T : MICROSEC; PT : TIMER) return BOOLEAN;  
    function GTE (PT : TIMER; T : MICROSEC) return BOOLEAN;  
    function GTE (T : MICROSEC; PT : TIMER) return BOOLEAN;  
    function EQU (PT : TIMER; T : MICROSEC) return BOOLEAN;  
    function EQU (T : MICROSEC; PT : TIMER) return BOOLEAN;

private  
    type STATE is (INITIAL, RUNNING, STOPPED);  
    type TIMER is  
        record  
            START\_TIME,  
            STOP\_TIME : CALENDAR.TIME;  
            ELAPSED\_TIME : DURATION;  
            PRESENT\_STATE : STATE;  
        end record;

end TIMERS;

with CALENDAR;  
use CALENDAR;  
package body TIMERS is

    CONVERSION\_FACTOR : constant DURATION := 1000000.0; -- converts elapsed  
  -- time to microsec's

```

function READ (NAME : in TIMER) return MICROSEC is
begin
  case NAME.PRESENT_STATE is

    when RUNNING => return MICROSEC(CLOCK
                                   - NAME.START_TIME
                                   + NAME.ELAPSED_TIME);

    when others => return MICROSEC(NAME.ELAPSED_TIME);
  end case;
end READ;

```

```

procedure RESET (NAME : in out TIMER) is
begin
  case NAME.PRESENT_STATE is

    when STOPPED => NAME.ELAPSED_TIME := 0.0;
                   NAME.PRESENT_STATE := INITIAL;

    when others => null;

  end case;
end RESET;

```

```

procedure START ( NAME : in out TIMER) is
begin
  case NAME.PRESENT_STATE is
    when RUNNING    => null;

    when others     => NAME.START_TIME := CALENDAR.CLOCK;
                     NAME.PRESENT_STATE := RUNNING;
  end case;
end START;

```

```

procedure STOP (NAME : in out TIMER) is
begin
  case NAME.PRESENT_STATE is
    when RUNNING    => NAME.ELAPSED_TIME := CALENDAR.CLOCK
                     - NAME.START_TIME

```

```

        + NAME.ELAPSED_TIME;
        NAME.PRESENT_STATE := STOPPED;

        when others      => null;
    end case;
end STOP;

function LT (PT : TIMER; T : MICROSEC) return BOOLEAN is

begin
    return FLOAT (PT.ELAPSED_TIME * CONVERSION_FACTOR) < FLOAT(T);
end LT;

function LT (T : MICROSEC; PT : TIMER) return BOOLEAN is

begin
    return LT (T,PT) = GTE (PT,T);
end LT;

function GT (PT : TIMER; T : MICROSEC) return BOOLEAN is

begin
    return FLOAT (PT.ELAPSED_TIME * CONVERSION_FACTOR) > FLOAT(T);
end GT;

function GT (T : MICROSEC; PT : TIMER) return BOOLEAN is

begin
    return GT (T,PT) = LTE (PT,T);
end GT;

function EQU (PT : TIMER; T : MICROSEC) return BOOLEAN is

begin
    return not LT(PT,T) and not GT (PT,T);
end EQU;

function EQU (T : MICROSEC; PT : TIMER) return BOOLEAN is

begin
    return not LT (PT,T) and not GT (PT,T);
end EQU;

function LTE (PT : TIMER; T : MICROSEC) return BOOLEAN is

```

```

begin
    return not GT (PT,T);
end LTE;

function LTE (T : MICROSEC; PT : TIMER) return BOOLEAN is
begin
    return not GT (PT,T);
end LTE;

function GTE (PT : TIMER; T : MICROSEC) return BOOLEAN is
begin
    return not LT (PT,T);
end GTE;

function GTE (T : MICROSEC; PT : TIMER) return BOOLEAN is
begin
    return not LT (PT,T);
end GTE;

end TIMERS;

```

## B. VSTRINGS

```
-- UNIT: generic package spec of VSTRINGS
--
-- FILES: vstring_spec.a in publiclib
--        related file is vstring_body.a in publiclib
--
-- PURPOSE: An implementation of the abstract data type "variable-length
--          string."
--
-- DESCRIPTION: This package provides a private type VSTRING. VSTRING objects
--              are "strings" that have a length between zero and LAST, where
--              LAST is the generic parameter supplied in the package
--              instantiation.
--
--              In addition to the type VSTRING, a subtype and two constants
--              are declared. The subtype STRINDEX is an index to a VSTRING,
--              The STRINDEX constant FIRST is an index to the first character
--              of the string, and the VSTRING constant NUL is a VSTRING of
--              length zero. NUL is the default initial value of a VSTRING.
--
--              The following sets of functions, procedures, and operators
--              are provided as operations on the type VSTRING:
--
--              ATTRIBUTE FUNCTIONS: LEN, MAX, STR, CHAR
--              The attribute functions return the characteristics of
--              a VSTRING.
--
--              COMPARISON OPERATORS: "=", "/=", "<", ">", "<=", ">="
--              The comparison operators are the same as for the predefined
--              type STRING.
--
--              INPUT/OUTPUT PROCEDURES: GET, GET_LINE, PUT, PUT_LINE
--
--              The input/output procedures are similar to those for the
--              predefined type STRING, with the following exceptions:
--
--              - GET has an optional parameter LENGTH, which indicates
--                the number of characters to get (default is LAST).
--
--              - GET_LINE does not have a parameter to return the length
--                of the string (the LEN function should be used instead).
--
--              EXTRACTION FUNCTIONS: SLICE, SUBSTR, DELETE
--              The SLICE function returns the slice of a VSTRING between
--              two indices (equivalent to STR(X)(A .. B)).
--
--              SUBSTR returns a substring of a VSTRING taken from a given
--              index and extending a given length.
```



```

--      The DELETE function returns the VSTRING which results from
--      removing the slice between two indices.
--
--      EDITING FUNCTIONS: INSERT, APPEND, REPLACE
--      The editing functions return the VSTRING which results from
--      inserting, appending, or replacing at a given index with a
--      VSTRING, STRING, or CHARACTER. The index must be in the
--      current range of the VSTRING; i.e., zero cannot be used.
--
--      CONCATENATION OPERATOR: "&"
--      The concatenation operator is the same as for the type
--      STRING. It should be used instead of APPEND when the
--      APPEND would always be after the last character.
--
--      POSITION FUNCTIONS: INDEX, RINDEX
--      The position functions return an index to the Nth occurrence
--      of a VSTRING, STRING, or CHARACTER from the front or back
--      of a VSTRING. Zero is returned if the search is not
--      successful.
--
--      CONVERSION FUNCTIONS AND OPERATOR: VSTR, CONVERT, "+"
--      VSTR converts a STRING or a CHARACTER to a VSTRING.
--
--      CONVERT is a generic function which can be instantiated to
--      convert from any given variable-length string to another,
--      provided the FROM type has a function equivalent to STR
--      defined for it, and that the TO type has a function equiv-
--      alent to VSTR defined for it. This provides a means for
--      converting between VSTRINGS declared in separate instanti-
--      ations of VSTRINGS. When instantiating CONVERT for
--      VSTRINGS, the STR and VSTR functions are implicitly defined,
--      provided that they have been made visible (by a use clause).
--
--      Note: CONVERT is NOT implicitly associated with the type
--      VSTRING declared in this package (since it would not be a
--      derivable function (see RM 3.4(11))).
--
--      Caution: CONVERT cannot be instantiated directly with the
--      names VSTR and STR, since the name of the subprogram being
--      declared would hide the generic parameters with the same
--      names (see RM 8.3(16)). CONVERT can be instantiated with
--      the operator "+", and any instantiation of CONVERT can
--      subsequently be renamed VSTR or STR.
--
--      Example: Given two VSTRINGS instantiations X and Y:
--      function "+" is new X.CONVERT(X.VSTRING, Y.VSTRING);
--      function "+" is new X.CONVERT(Y.VSTRING, X.VSTRING);
--
--      (Y.CONVERT could have been used in place of X.CONVERT)
--
--      function VSTR(A : X.VSTRING) return Y.VSTRING renames "+";

```

```
--      function VSTR(A : Y.VSTRING) return X.VSTRING renames "+";
--
--      "+" is equivalent to VSTR. It is supplied as a short-hand
--      notation for the function. The "+" operator cannot immedi-
--      ately follow the "&" operator; use ... & (+ ...) instead.
```

#### -- DISCUSSION:

```
--      This package implements the type "variable-length string" (vstring)
--      using generics. The alternative approaches are to use a discriminant
--      record in which the discriminant controls the length of a STRING inside
--      the record, or a record containing an access type which points to a
--      string, which can be deallocated and reallocated when necessary.
```

#### -- Advantages of this package:

- \* The other approaches force the vstring to be a limited private
-- type. Thus, their vstrings cannot appear on the left side of
-- the assignment operator; ie., their vstrings cannot be given
-- initial values or values by direct assignment. This package
-- uses a private type; therefore, these things can be done.
- \* The other approach stores the vstring in a string whose length
-- is determined dynamically. This package uses a fixed length
-- string. This difference might be reflected in faster and more
-- consistent execution times (this has NOT been verified).

#### -- Disadvantages of this package:

- \* Different instantiations must be used to declare vstrings with
-- different maximum lengths (this may be desirable, since
-- CONSTRAINT\_ERROR will be raised if the maximum is exceeded).
- \* A second declaration is required to give the type declared by
-- the instantiation a name other than "VSTRING."
- \* The storage required for a vstring is determined by the generic
-- parameter LAST and not the actual length of its contents. Thus,
-- each object is allocated the maximum amount of storage, regardless
-- of its actual size.

#### -- MISCELLANEOUS:

```
--      Constraint checking is done explicitly in the code; thus, it cannot
--      be suppressed. On the other hand, constraint checking is not lost
--      if pragma suppress is supplied to the compilation (-S option)
--      (The robustness of the explicit constraint checking has NOT been
--      determined).
```

```
--      Compiling with the optimizer (-O option) may significantly reduce
--      the size (and possibly execution time) of the resulting executable.
```

```
--      Compiling an instantiation of VSTRINGS is roughly equivalent to
--      recompiling VSTRINGS. Since this takes a significant amount of time,
--      and the instantiation does not depend on any other library units,
```

```

--      it is STRONGLY recommended that the instantiation be compiled
--      separately, and thus done only ONCE.
--
--  USAGE: with VSTRINGS;
--          package package_name is new VSTRINGS(maximum_length);
-- .....
with TEXT_IO; use TEXT_IO;
generic
    LAST : NATURAL;
package VSTRINGS is

    subtype STRINDEX is NATURAL;
    FIRST : constant STRINDEX := STRINDEX'FIRST + 1;
    type VSTRING is private;
    NUL : constant VSTRING;

-- Attributes of a VSTRING

    function LEN(FROM : VSTRING) return STRINDEX;
    function MAX(FROM : VSTRING) return STRINDEX;
    function STR(FROM : VSTRING) return STRING;
    function CHAR(FROM: VSTRING; POSITION : STRINDEX := FIRST)
        return CHARACTER;

-- Comparisons

    function "<" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;
    function ">" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;
    function "<=" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;
    function ">=" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;
    function equal (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;
    function notequal (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN;

-- Input/Output

    procedure PUT(FILE : in FILE_TYPE; ITEM : in VSTRING);
    procedure PUT(ITEM : in VSTRING);

    procedure PUT_LINE(FILE : in FILE_TYPE; ITEM : in VSTRING);
    procedure PUT_LINE(ITEM : in VSTRING);

    procedure GET(FILE : in FILE_TYPE; ITEM : out VSTRING;
        LENGTH : in STRINDEX := LAST);
    procedure GET(ITEM : out VSTRING; LENGTH : in STRINDEX := LAST);

    procedure GET_LINE(FILE : in FILE_TYPE; ITEM : in out VSTRING);
    procedure GET_LINE(ITEM : in out VSTRING);

-- Extraction

```

```

function SLICE(FROM: VSTRING; FRONT, BACK : STRINDEX) return VSTRING;
function SUBSTR(FROM: VSTRING; START, LENGTH: STRINDEX) return VSTRING;
function DELETE(FROM: VSTRING; FRONT, BACK : STRINDEX) return VSTRING;

-- Editing

function INSERT(TARGET: VSTRING; ITEM: VSTRING;
                POSITION: STRINDEX := FIRST) return VSTRING;
function INSERT(TARGET: VSTRING; ITEM: STRING;
                POSITION: STRINDEX := FIRST) return VSTRING;
function INSERT(TARGET: VSTRING; ITEM: CHARACTER;
                POSITION: STRINDEX := FIRST) return VSTRING;

function APPEND(TARGET: VSTRING; ITEM: VSTRING; POSITION: STRINDEX)
    return VSTRING;
function APPEND(TARGET: VSTRING; ITEM: STRING; POSITION: STRINDEX)
    return VSTRING;
function APPEND(TARGET: VSTRING; ITEM: CHARACTER; POSITION: STRINDEX)
    return VSTRING;

function APPEND(TARGET: VSTRING; ITEM: VSTRING) return VSTRING;
function APPEND(TARGET: VSTRING; ITEM: STRING) return VSTRING;
function APPEND(TARGET: VSTRING; ITEM: CHARACTER) return VSTRING;

function REPLACE(TARGET: VSTRING; ITEM: VSTRING;
                 POSITION: STRINDEX := FIRST) return VSTRING;
function REPLACE(TARGET: VSTRING; ITEM: STRING;
                 POSITION: STRINDEX := FIRST) return VSTRING;
function REPLACE(TARGET: VSTRING; ITEM: CHARACTER;
                 POSITION: STRINDEX := FIRST) return VSTRING;

-- Concatenation

function "&" (LEFT: VSTRING; RIGHT : VSTRING) return VSTRING;
function "&" (LEFT: VSTRING; RIGHT : STRING) return VSTRING;
function "&" (LEFT: VSTRING; RIGHT : CHARACTER) return VSTRING;
function "&" (LEFT: STRING; RIGHT : VSTRING) return VSTRING;
function "&" (LEFT: CHARACTER; RIGHT : VSTRING) return VSTRING;

-- Determine the position of a substring

function INDEX(WHOLE: VSTRING; PART: VSTRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX;
function INDEX(WHOLE : VSTRING; PART : STRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX;
function INDEX(WHOLE : VSTRING; PART : CHARACTER; OCCURRENCE : NATURAL := 1)
    return STRINDEX;

function RINDEX(WHOLE: VSTRING; PART: VSTRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX;

```

```

function RINDEX(WHOLE : VSTRING; PART : STRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX;
function RINDEX(WHOLE : VSTRING; PART : CHARACTER; OCCURRENCE : NATURAL := 1)
    return STRINDEX;

-- Conversion from other associated types

function VSTR(FROM : STRING) return VSTRING;
function VSTR(FROM : CHARACTER) return VSTRING;
function "+" (FROM : STRING) return VSTRING;
function "+" (FROM : CHARACTER) return VSTRING;

generic
    type FROM is private;
    type TO is private;
    with function STR(X : FROM) return STRING is <>;
    with function VSTR(Y : STRING) return TO is <>;
    function CONVERT(X : FROM) return TO;

private
    type VSTRING is
        record
            LEN : STRINDEX := STRINDEX'FIRST;
            VALUE : STRING(FIRST .. LAST) := (others => ASCII.NUL);
        end record;

    NUL : constant VSTRING := (STRINDEX'FIRST, (others => ASCII.NUL));
end VSTRINGS;
--
-- ..... --
--
-- DISTRIBUTION AND COPYRIGHT:
--
-- This software is released to the Public Domain (note:
--   software released to the Public Domain is not subject
--   to copyright protection).
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-- test the software thoroughly before relying on it. The user
-- must assume the entire risk and liability of using this
-- software.

```

```

--
-- In no event shall any person or organization of people be
-- held responsible for any direct, indirect, consequential
-- or inconsequential damages or lost profits.

-- UNIT: generic package body of VSTRINGS
--
-- FILES: vstring_body.a in publiclib
--        related file is vstring_spec.a in publiclib
--
-- PURPOSE: An implementation of the abstract data type "variable-length
--          string."
--
-- DESCRIPTION: This package provides a private type VSTRING. VSTRING objects
--              are "strings" that have a length between zero and LAST, where
--              LAST is the generic parameter supplied in the package
--              instantiation.

--              In addition to the type VSTRING, a subtype and two constants
--              are declared. The subtype STRINDEX is an index to a VSTRING,
--              The STRINDEX constant FIRST is an index to the first character
--              of the string, and the VSTRING constant NUL is a VSTRING of
--              length zero. NUL is the default initial value of a VSTRING.

--              The following sets of functions, procedures, and operators
--              are provided as operations on the type VSTRING:

--              ATTRIBUTE FUNCTIONS: LEN, MAX, STR, CHAR
--              The attribute functions return the characteristics of
--              a VSTRING.

--              COMPARISON OPERATORS: "=", "/=", "<", ">", "<=", ">="
--              The comparison operators are the same as for the predefined
--              type STRING.

--              INPUT/OUTPUT PROCEDURES: GET, GET_LINE, PUT, PUT_LINE

--              The input/output procedures are similar to those for the
--              predefined type STRING, with the following exceptions:

--              - GET has an optional parameter LENGTH, which indicates
--                the number of characters to get (default is LAST).

--              - GET_LINE does not have a parameter to return the length
--                of the string (the LEN function should be used instead).

--              EXTRACTION FUNCTIONS: SLICE, SUBSTR, DELETE
--              The SLICE function returns the slice of a VSTRING between
--              two indices (equivalent to STR(X)(A .. B)).

```

```

--      SUBSTR returns a substring of a VSTRING taken from a given
--      index and extending a given length.
--
--      The DELETE function returns the VSTRING which results from
--      removing the slice between two indices.
--
--      EDITING FUNCTIONS: INSERT, APPEND, REPLACE
--      The editing functions return the VSTRING which results from
--      inserting, appending, or replacing at a given index with a
--      VSTRING, STRING, or CHARACTER. The index must be in the
--      current range of the VSTRING; i.e., zero cannot be used.
--
--      CONCATENATION OPERATOR: "&"
--      The concatenation operator is the same as for the type
--      STRING. It should be used instead of APPEND when the
--      APPEND would always be after the last character.
--
--      POSITION FUNCTIONS: INDEX, RINDEX
--      The position functions return an index to the Nth occurrence
--      of a VSTRING, STRING, or CHARACTER from the front or back
--      of a VSTRING. Zero is returned if the search is not
--      successful.
--
--      CONVERSION FUNCTIONS AND OPERATOR: VSTR, CONVERT, "+"
--      VSTR converts a STRING or a CHARACTER to a VSTRING.
--
--      CONVERT is a generic function which can be instantiated to
--      convert from any given variable-length string to another,
--      provided the FROM type has a function equivalent to STR
--      defined for it, and that the TO type has a function equiv-
--      alent to VSTR defined for it. This provides a means for
--      converting between VSTRINGS declared in separate instant-
--      iations of VSTRINGS. When instantiating CONVERT for
--      VSTRINGS, the STR and VSTR functions are implicitly defined,
--      provided that they have been made visible (by a use clause).
--
--      Note: CONVERT is NOT implicitly associated with the type
--      VSTRING declared in this package (since it would not be a
--      derivable function (see RM 3.4(11))).
--
--      Caution: CONVERT cannot be instantiated directly with the
--      names VSTR and STR, since the name of the subprogram being
--      declared would hide the generic parameters with the same
--      names (see RM 8.3(16)). CONVERT can be instantiated with
--      the operator "+", and any instantiation of CONVERT can
--      subsequently be renamed VSTR or STR.
--
--      Example: Given two VSTRINGS instantiations X and Y:
--      function "+" is new X.CONVERT(X.VSTRING, Y.VSTRING);
--      function "+" is new X.CONVERT(Y.VSTRING, X.VSTRING);

```

```

--          (Y.CONVERT could have been used in place of X.CONVERT)
--
--          function VSTR(A : X.VSTRING) return Y.VSTRING renames "+";
--          function VSTR(A : Y.VSTRING) return X.VSTRING renames "+";
--
--          "+" is equivalent to VSTR. It is supplied as a short-hand
--          notation for the function. The "+" operator cannot immediately
--          follow the "&" operator; use ... & (+ ...) instead.
-- DISCUSSION:
--
--          This package implements the type "variable-length string" (vstring)
--          using generics. The alternative approaches are to use a discriminant
--          record in which the discriminant controls the length of a STRING inside
--          the record, or a record containing an access type which points to a
--          string, which can be deallocated and reallocated when necessary.
--
--          Advantages of this package:
--          * The other approaches force the vstring to be a limited private
--            type. Thus, their vstrings cannot appear on the left side of
--            the assignment operator; ie., their vstrings cannot be given
--            initial values or values by direct assignment. This package
--            uses a private type; therefore, these things can be done.
--
--          * The other approach stores the vstring in a string whose length
--            is determined dynamically. This package uses a fixed length
--            string. This difference might be reflected in faster and more
--            consistent execution times (this has NOT been verified).
--
--          Disadvantages of this package:
--          * Different instantiations must be used to declare vstrings with
--            different maximum lengths (this may be desirable, since
--            CONSTRAINT_ERROR will be raised if the maximum is exceeded).
--
--          * A second declaration is required to give the type declared by
--            the instantiation a name other than "VSTRING."
--
--          * The storage required for a vstring is determined by the generic
--            parameter LAST and not the actual length of its contents. Thus,
--            each object is allocated the maximum amount of storage, regardless
--            of its actual size.
-- MISCELLANEOUS:
--          Constraint checking is done explicitly in the code; thus, it cannot
--          be suppressed. On the other hand, constraint checking is not lost
--          if pragma suppress is supplied to the compilation (-S option)
--          (The robustness of the explicit constraint checking has NOT been
--          determined).
--
--          Compiling with the optimizer (-O option) may significantly reduce
--          the size (and possibly execution time) of the resulting executable.
--

```



```

--    Compiling an instantiation of VSTRINGS is roughly equivalent to
--    recompiling VSTRINGS.  Since this takes a significant amount of time,
--    and the instantiation does not depend on any other library units,
--    it is STRONGLY recommended that the instantiation be compiled
--    separately, and thus done only ONCE.
--
--  USAGE: with VSTRINGS;
--          package package_name is new VSTRINGS(maximum_length);
--  .....
package body VSTRINGS is

    -- local declarations

    FILL_CHAR : constant CHARACTER := ASCII.NUL;

    procedure FORMAT( THE_STRING : in out VSTRING; OLDLEN : in STRINDEX := LAST) is
        -- fill the string with FILL_CHAR to null out old values

        begin -- FORMAT (Local Procedure)
            THE_STRING.VALUE( THE_STRING.LEN + 1 .. OLDLEN ) :=
                (others => FILL_CHAR);
        end FORMAT;

    -- bodies of visible operations

    function LEN( FROM : VSTRING) return STRINDEX is

        begin -- LEN
            return( FROM.LEN );
        end LEN;

    function MAX( FROM : VSTRING) return STRINDEX is
        begin -- MAX
            return( LAST );
        end MAX;

    function STR( FROM : VSTRING) return STRING is
        begin -- STR
            return( FROM.VALUE( FIRST .. FROM.LEN ) );
        end STR;

    function CHAR( FROM : VSTRING; POSITION : STRINDEX := FIRST)
        return CHARACTER is

        begin -- CHAR
            if POSITION not in FIRST .. FROM.LEN
            then raise CONSTRAINT_ERROR;

```

```

        end if;
        return(FROM.VALUE(POSITION));
    end CHAR;

function "<" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- "<"
        return(LEFT.VALUE < RIGHT.VALUE);
    end "<";

function ">" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- ">"
        return(LEFT.VALUE > RIGHT.VALUE);
    end ">";

function "<=" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- "<="
        return(LEFT.VALUE <= RIGHT.VALUE);
    end "<=";

function ">=" (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- ">="
        return(LEFT.VALUE >= RIGHT.VALUE);
    end ">=";

function equal (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- equal
        return(LEFT.VALUE = RIGHT.VALUE);
    end equal;

function notequal (LEFT: VSTRING; RIGHT: VSTRING) return BOOLEAN is
    begin -- notequal
        return(LEFT.VALUE /= RIGHT.VALUE);
    end notequal;

procedure PUT(FILE : in FILE_TYPE; ITEM : in VSTRING) is
    begin -- PUT
        PUT(FILE, ITEM.VALUE(FIRST .. ITEM.LEN));
    end PUT;

procedure Put(ITEM : in VSTRING) is
    begin -- PUT
        PUT(ITEM.VALUE(FIRST .. ITEM.LEN));
    end PUT;

procedure PUT_LINE(FILE : in FILE_TYPE; ITEM : in VSTRING) is

```

```

begin -- PUT_LINE
    PUT_LINE(FILE, ITEM.VALUE(FIRST .. ITEM.LEN));
end PUT_LINE;

procedure PUT_LINE(ITEM : in VSTRING) is
begin -- PUT_LINE
    PUT_LINE(ITEM.VALUE(FIRST .. ITEM.LEN));
end PUT_LINE;

procedure GET(FILE : in FILE_TYPE; ITEM : out VSTRING;
    LENGTH : in STRINDEX := LAST) is
begin -- GET
    if LENGTH not in FIRST .. LAST
    then raise CONSTRAINT_ERROR;
    end if;

    ITEM := NUL;
    for INDEX in FIRST .. LENGTH loop
        GET(FILE, ITEM.VALUE(INDEX));
        ITEM.LEN := INDEX;
    end loop;
end GET;

procedure GET(ITEM : out VSTRING; LENGTH : in STRINDEX := LAST) is
begin -- GET
    if LENGTH not in FIRST .. LAST
    then raise CONSTRAINT_ERROR;
    end if;

    ITEM := NUL;
    for INDEX in FIRST .. LENGTH loop
        GET(ITEM.VALUE(INDEX));
        ITEM.LEN := INDEX;
    end loop;
end GET;

procedure GET_LINE(FILE : in FILE_TYPE; ITEM : in out VSTRING) is

    OLDLEN : constant STRINDEX := ITEM.LEN;

begin -- GET_LINE
    GET_LINE(FILE, ITEM.VALUE, ITEM.LEN);
    FORMAT(ITEM, OLDLEN);
end GET_LINE;

procedure GET_LINE(ITEM : in out VSTRING) is

    OLDLEN : constant STRINDEX := ITEM.LEN;

```

```

begin -- GET_LINE
  GET_LINE(ITEM.VALUE, ITEM.LEN);
  FORMAT(ITEM, OLDLEN);
end GET_LINE;

function SLICE(FROM : VSTRING; FRONT, BACK : STRINDEX) return VSTRING is

begin -- SLICE
  if ((FRONT not in FIRST .. FROM.LEN) or else
      (BACK not in FIRST .. FROM.LEN)) and then FRONT <= BACK
  then raise CONSTRAINT_ERROR;
  end if;

  return(Vstr(FROM.VALUE(FRONT .. BACK)));
end SLICE;

function SUBSTR(FROM : VSTRING; START, LENGTH : STRINDEX) return VSTRING is

begin -- SUBSTR
  if (START not in FIRST .. FROM.LEN) or else
      ((START + LENGTH - 1 not in FIRST .. FROM.LEN)
       and then (LENGTH > 0))
  then raise CONSTRAINT_ERROR;
  end if;

  return(Vstr(FROM.VALUE(START .. START + LENGTH - 1)));
end SUBSTR;

function DELETE(FROM : VSTRING; FRONT, BACK : STRINDEX) return VSTRING is

  TEMP : VSTRING := FROM;

begin -- DELETE
  if ((FRONT not in FIRST .. FROM.LEN) or else
      (BACK not in FIRST .. FROM.LEN)) and then FRONT <= BACK
  then raise CONSTRAINT_ERROR;
  end if;

  if FRONT > BACK then return(FROM); end if;
  TEMP.LEN := FROM.LEN - (BACK - FRONT) - 1;

  TEMP.VALUE(FRONT .. TEMP.LEN) := FROM.VALUE(BACK + 1 .. FROM.LEN);
  FORMAT(TEMP, FROM.LEN);
  return(TEMP);
end DELETE;

function INSERT(TARGET: VSTRING; ITEM: VSTRING;

```

```

        POSITION : STRINDEX := FIRST) return VSTRING is

TEMP : VSTRING;

begin -- INSERT
    if POSITION not in FIRST .. TARGET.LEN
        then raise CONSTRAINT_ERROR;
        end if;

    if TARGET.LEN + ITEM.LEN > LAST
        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := TARGET.LEN + ITEM.LEN;
        end if;

    TEMP.VALUE(FIRST .. POSITION - 1) := TARGET.VALUE(FIRST .. POSITION - 1);
    TEMP.VALUE(POSITION .. (POSITION + ITEM.LEN - 1)) :=
        ITEM.VALUE(FIRST .. ITEM.LEN);
    TEMP.VALUE((POSITION + ITEM.LEN) .. TEMP.LEN) :=
        TARGET.VALUE(POSITION .. TARGET.LEN);

    return(TEMP);
end INSERT;

function INSERT(TARGET: VSTRING; ITEM: STRING;
                POSITION : STRINDEX := FIRST) return VSTRING is
begin -- INSERT
    return INSERT(TARGET, VSTR(ITEM), POSITION);
end INSERT;

function INSERT(TARGET: VSTRING; ITEM: CHARACTER;
                POSITION : STRINDEX := FIRST) return VSTRING is
begin -- INSERT
    return INSERT(TARGET, VSTR(ITEM), POSITION);
end INSERT;

function APPEND(TARGET: VSTRING; ITEM: VSTRING; POSITION : STRINDEX)
                return VSTRING is

TEMP : VSTRING;
POS : STRINDEX := POSITION;

begin -- APPEND
    if POSITION not in FIRST .. TARGET.LEN
        then raise CONSTRAINT_ERROR;
        end if;

    if TARGET.LEN + ITEM.LEN > LAST
        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := TARGET.LEN + ITEM.LEN;
        end if;

```

```

    TEMP.VALUE(FIRST .. POS) := TARGET.VALUE(FIRST .. POS);
    TEMP.VALUE(POS + 1 .. (POS + ITEM.LEN)) := ITEM.VALUE(FIRST .. ITEM.LEN);
    TEMP.VALUE((POS + ITEM.LEN + 1) .. TEMP.LEN) :=
        TARGET.VALUE(POS + 1 .. TARGET.LEN);

    return(TEMP);
end APPEND;

function APPEND(TARGET: VSTRING; ITEM: STRING; POSITION : STRINDEX)
    return VSTRING is
begin -- APPEND
    return APPEND(TARGET, VSTR(ITEM), POSITION);
end APPEND;

function APPEND(TARGET: VSTRING; ITEM: CHARACTER; POSITION : STRINDEX)
    return VSTRING is
begin -- APPEND
    return APPEND(TARGET, VSTR(ITEM), POSITION);
end APPEND;

function APPEND(TARGET: VSTRING; ITEM: VSTRING) return VSTRING is
begin -- APPEND
    return(APPEND(TARGET, ITEM, TARGET.LEN));
end APPEND;

function APPEND(TARGET: VSTRING; ITEM: STRING) return VSTRING is
begin -- APPEND
    return(APPEND(TARGET, VSTR(ITEM), TARGET.LEN));
end APPEND;

function APPEND(TARGET: VSTRING; ITEM: CHARACTER) return VSTRING is
begin -- APPEND
    return(APPEND(TARGET, VSTR(ITEM), TARGET.LEN));
end APPEND;

function REPLACE(TARGET: VSTRING; ITEM: VSTRING;
    POSITION : STRINDEX := FIRST) return VSTRING is

    TEMP : VSTRING;

begin -- REPLACE
    if POSITION not in FIRST .. TARGET.LEN
    then raise CONSTRAINT_ERROR;
    end if;

    if POSITION + ITEM.LEN - 1 <= TARGET.LEN
    then TEMP.LEN := TARGET.LEN;
    elsif POSITION + ITEM.LEN - 1 > LAST

```

```

        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := POSITION + ITEM.LEN - 1;
    end if;

    TEMP.VALUE(FIRST .. POSITION - 1) := TARGET.VALUE(FIRST .. POSITION - 1);
    TEMP.VALUE(POSITION .. (POSITION + ITEM.LEN - 1)) :=
        ITEM.VALUE(FIRST .. ITEM.LEN);
    TEMP.VALUE((POSITION + ITEM.LEN) .. TEMP.LEN) :=
        TARGET.VALUE((POSITION + ITEM.LEN) .. TARGET.LEN);

    return(TEMP);
end REPLACE;

function REPLACE(TARGET: VSTRING; ITEM: STRING;
    POSITION : STRINDEX := FIRST) return VSTRING is
begin -- REPLACE
    return REPLACE(TARGET, VSTR(ITEM), POSITION);
end REPLACE;

function REPLACE(TARGET: VSTRING; ITEM: CHARACTER;
    POSITION : STRINDEX := FIRST) return VSTRING is
begin -- REPLACE
    return REPLACE(TARGET, VSTR(ITEM), POSITION);
end REPLACE;

function "&"(LEFT:VSTRING; RIGHT : VSTRING) return VSTRING is

    TEMP : VSTRING;

begin -- "&"
    if LEFT.LEN + RIGHT.LEN > LAST
        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := LEFT.LEN + RIGHT.LEN;
        end if;

    TEMP.VALUE(FIRST .. TEMP.LEN) := LEFT.VALUE(FIRST .. LEFT.LEN) &
        RIGHT.VALUE(FIRST .. RIGHT.LEN);
    return(TEMP);
end "&";

function "&"(LEFT:VSTRING; RIGHT : STRING) return VSTRING is
begin -- "&"
    return LEFT & VSTR(RIGHT);
end "&";

function "&"(LEFT:VSTRING; RIGHT : CHARACTER) return VSTRING is
begin -- "&"
    return LEFT & VSTR(RIGHT);
end "&";

```

```

function "&"(LEFT : STRING; RIGHT : VSTRING) return VSTRING is
begin -- "&"
    return VSTR(LEFT) & RIGHT;
end "&";

```

```

function "&"(LEFT : CHARACTER; RIGHT : VSTRING) return VSTRING is
begin -- "&"
    return VSTR(LEFT) & RIGHT;
end "&";

```

```

Function INDEX(WHOLE : VSTRING; PART : VSTRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX is

```

```

    NOT_FOUND : constant NATURAL := 0;
    INDEX : NATURAL := FIRST;
    COUNT : NATURAL := 0;

```

```

begin -- INDEX
    if PART = NUL then return(NOT_FOUND); -- by definition
    end if;

```

```

    while INDEX + PART.LEN - 1 <= WHOLE.LEN and then COUNT < OCCURRENCE loop
        if WHOLE.VALUE(INDEX .. PART.LEN + INDEX - 1) =
            PART.VALUE(1 .. PART.LEN)
            then COUNT := COUNT + 1;
            end if;
        INDEX := INDEX + 1;
    end loop;

```

```

    if COUNT = OCCURRENCE
        then return(INDEX - 1);
        else return(NOT_FOUND);
    end if;
end INDEX;

```

```

Function INDEX(WHOLE : VSTRING; PART : STRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX is

```

```

begin -- Index
    return(Index(WHOLE, VSTR(PART), OCCURRENCE));
end INDEX;

```

```

Function INDEX(WHOLE : VSTRING; PART : CHARACTER; OCCURRENCE : NATURAL := 1)
    return STRINDEX is

```

```

begin -- Index
    return(Index(WHOLE, VSTR(PART), OCCURRENCE));
end INDEX;

```



```
function RINDEX(WHOLE: VSTRING; PART:VSTRING; OCCURRENCE:NATURAL := 1)
    return STRINDEX is
```

```
    NOT_FOUND : constant NATURAL := 0;
    INDEX : INTEGER := WHOLE.LEN - (PART.LEN - 1);
    COUNT : NATURAL := 0;
```

```
begin -- RINDEX
    if PART = NUL then return(NOT_FOUND); -- by definition
    end if;
```

```
    while INDEX >= FIRST and then COUNT < OCCURRENCE loop
        if WHOLE.VALUE(INDEX .. PART.LEN + INDEX - 1) =
            PART.VALUE(1 .. PART.LEN)
            then COUNT := COUNT + 1;
            end if;
        INDEX := INDEX - 1;
    end loop;
```

```
    if COUNT = OCCURRENCE
    then
        if COUNT > 0
            then return(INDEX + 1);
            else return(NOT_FOUND);
            end if;
        else return(NOT_FOUND);
        end if;
    end RINDEX;
```

```
Function RINDEX(WHOLE : VSTRING; PART : STRING; OCCURRENCE : NATURAL := 1)
    return STRINDEX is
```

```
begin -- Rindex
    return(RINDEX(WHOLE, VSTR(PART), OCCURRENCE));
end RINDEX;
```

```
Function RINDEX(WHOLE : VSTRING; PART : CHARACTER; OCCURRENCE : NATURAL := 1)
    return STRINDEX is
```

```
begin -- Rindex
    return(RINDEX(WHOLE, VSTR(PART), OCCURRENCE));
end RINDEX;
```

```
function VSTR(FROM : CHARACTER) return VSTRING is
```

```
    TEMP : VSTRING;
```

```
begin -- VSTR
```

```

    if LAST < 1
        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := 1;
        end if;

    TEMP.VALUE(FIRST) := FROM;
    return(TEMP);
end VSTR;

function VSTR(FROM : STRING) return VSTRING is

    TEMP : VSTRING;

begin -- VSTR
    if FROM'LENGTH > LAST
        then raise CONSTRAINT_ERROR;
        else TEMP.LEN := FROM'LENGTH;
        end if;

    TEMP.VALUE(FIRST .. FROM'LENGTH) := FROM;
    return(TEMP);
end VSTR;

Function "+" (FROM : STRING) return VSTRING is
begin -- "+"
    return(VSTR(FROM));
end "+";

Function "+" (FROM : CHARACTER) return VSTRING is
begin
    return(VSTR(FROM));
end "+";

function CONVERT(X : FROM) return TO is

begin -- CONVERT
    return(VSTR(STR(X)));
end CONVERT;
end VSTRINGS;

-- .....
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### C. List\_Single\_Unbounded\_Unmanaged

```
generic
    type Item is private;
package List_Single_Unbounded_Unmanaged is

    type List is private;

    Null_List : constant List;

    procedure Construct (The_Item      : in Item;
                        And_The_List : in out List);

    function Is_Null (The_List : in List) return Boolean;
    function Head_Of (The_List : in List) return Item;
    function Tail_Of (The_List : in List) return List;

    Overflow      : exception;
    List_Is_Null : exception;

private
    type Node;
    type List is access Node;
    Null_List : constant List := null;
end List_Single_Unbounded_Unmanaged;

package body List_Single_Unbounded_Unmanaged is

    type Node is
        record
            The_Item : Item;
            Next      : List;
        end record;

    procedure Construct (The_Item      : in Item;
                        And_The_List : in out List) is
    begin
        And_The_List := new Node'(The_Item => The_Item,
                                   Next      => And_The_List);
    exception
        when Storage_Error =>
            raise Overflow;
    end Construct;

    function Is_Null (The_List : in List) return Boolean is
    begin
        return (The_List = null);
    end Is_Null;

    function Head_Of (The_List : in List) return Item is
```

```

begin
    return The_List.The_Item;
exception
    when Constraint_Error =>
        raise List_Is_Null;
end Head_Of;

function Tail_Of (The_List : in List) return List is
begin
    return The_List.Next;
exception
    when Constraint_Error =>
        raise List_Is_Null;
end Tail_Of;

end List_Single_Unbounded_Unmanaged;

```

#### D. PRIORITY\_DEFINITIONS

```
with SYSTEM;  
use SYSTEM;  
package PRIORITY_DEFINITIONS is  
    BUFFER_PRIORITY : constant priority := 10;  
    STATIC_SCHEDULE_PRIORITY : constant priority := 8;  
    DYNAMIC_SCHEDULE_PRIORITY : constant priority := 1;  
end PRIORITY_DEFINITIONS;
```

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